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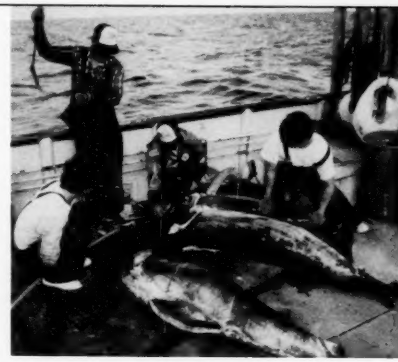

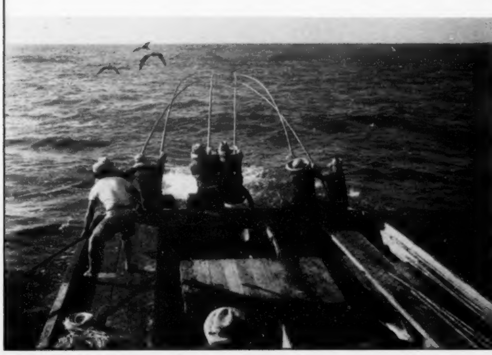

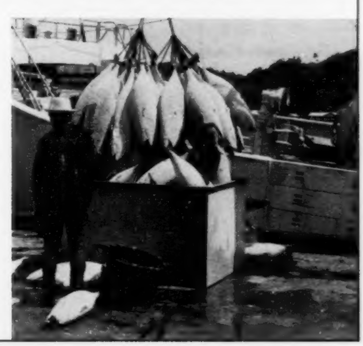

Fisheries of Hawaii and U.S.-associated Pacific Islands

Marine Fisheries
REVIEW

On the cover: Fisheries of Hawaii and U.S.-associated Pacific Islands. NMFS photos.

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The Fisheries of Hawaii and U.S.-associated Pacific Islands

Preface

In the late 1980's and early 1990's, significant changes occurred in the fisheries of Hawaii. Expansion and diversification of pelagic fisheries and growth (including industrialization) of fisheries that, in at least some cases, had been largely recreational or artisanal led to fear of overfishing and problems in allocation among fishery sectors. Combined with establishment of limited entry programs in Hawaii fisheries (bottomfish, longline, and lobster), this led to anticipation that similar growth might occur in Guam, the Northern Marianas, and American Samoa.

In examining the status of fisheries in Hawaii and the other U.S.-associated islands in the Pacific, however, it was evident that the availability of information was limited largely to annual reports, agency administrative reports and data reports. Nowhere was there a published source of reference information dealing with fisheries in this region available to scientists and the public.

A meeting of interested parties (and potential authors) late in 1991 at the U.S. National Marine Fisheries Service (NMFS) Honolulu Laboratory led to an agreement to develop a series of papers to address this shortcoming; participants agreed that papers summarizing these fisheries with up-to-date information otherwise available only in unpublished form would be quite useful.

The group decided to limit the scope of the volume to domestic, island-based (rather than distant-water) fisheries, thereby excluding tuna purse seine and albacore fisheries and island-based foreign fleets in the case of Guam and American Samoa. Each paper was to include information on the biology of the species involved, a synopsis of the fishery (including historical trends, gear and vessel types, data sources and collection, status of stocks, and a brief description of markets), current research and research needs, issues associated with management and regulation of the fishery, and future prospects. Because much of the source material for these papers comes from unpublished sources, however, it should be noted that restrictions on the citing of unpublished sources has been eased in this issue of *Marine Fisheries Review* to facilitate introducing the reader to some unconventional information sources. Readers interested in further information on, or copies of, these difficult-to-find materials are referred to the authors of the papers.

Virtually all papers planned for this volume were completed and provide comprehensive views of the fisheries. Lacking, however, is a paper on the fisheries of the Commonwealth of the Northern Mariana Islands (CNMI) which, although similar in geographic locality to Guam, has its own unique fisheries. For further information on CNMI, the reader is referred to Uchida (1983) for background and to Polovina et al. (1985), which summarizes the work conducted over several years in the "Resource Assessment Investigation of the Mariana Archipelago", or RAIOMA. This program was conducted by the NMFS Honolulu Laboratory. Other papers from this program describe specific fisheries: Deep bottomfish in Polovina (1985) and deep-sea shrimp in Ralston (1986). Unfortunately, the nearshore and artisanal fisheries are not described, although some information is available in Uchida (1983) and Smith (1988). For specific information on fisheries catch in CNMI, the reader is also referred to "Fisheries Statistics of the Western Pacific" (Hamm et al.[1] and preceding yearly volumes).

[1]Hamm, D. C., M. Quach, and R. Antonio. 1992. Fisheries statistics of the western Pacific, volume VIII. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-92-14, var. pagin.

Acknowledgments

This volume of papers would not have been possible without the efforts of many individuals. Obviously, the authors put in a great deal of work to meet (or nearly meet) deadlines for manuscripts and revisions. Editorial and graphics quality on many manuscripts benefited from the work of Judy Beasley and Deborah Yamaguchi. The quality of the papers was increased appreciably by the efforts of external reviewers, many of whom were authors of other papers. The following reviewers are acknowledged for providing critical comments on the manuscripts (individuals designated with an asterisk reviewed more than one manuscript).

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Fisheries and Marine Resources of Hawaii and the U.S.-associated Pacific Islands: An Introduction

GEORGE W. BOEHLERT

Introduction

Fisheries of Hawaii and the U.S. insular Pacific are quite different from typical industrial and recreational fisheries of the mainland U.S. Fisheries productivity in coastal waters of these tropical and subtropical islands may be similar to that in temperate continental shelf-slope fish communities (Marten and Polovina, 1982), but the higher species diversity results in more diverse, lower volume fisheries. Larger, commercial fisheries are often dependent upon deep water, slope-dwelling species or the highly migratory pelagics such as tunas and billfishes. Although land masses in this region are small, the U.S. Exclusive Economic Zone (EEZ) surrounding the island areas is immense, covering over 2 million square miles. Over this broad geographic expanse, a variety of cultural differences affect fishing practices, and even those practices present today are significantly different from the native approaches to fishing methods in Hawaii (Smith, 1993) and Guam (Hensley and Sherwood, 1993). Finally, variations in the population size and in the fishing pressure on the nearshore ecosystem are marked among islands, from the highly populated island of Oahu in Hawaii to sparsely populated islands elsewhere to the mostly uninhabited islands of the Northwestern Hawaiian Islands (NWHI) and Commonwealth of the Northern Mariana Islands (CNMI).

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ABSTRACT — The fisheries of Hawaii and other U.S.-associated islands in the Pacific Ocean are characterized by high diversity, both in the species exploited and the human cultures that exploit them. The commercial sector has undergone rapid growth in recent years, but recreational and subsistence sectors remain important. Information on these fisheries is generally not available in published form. This paper presents an overview and introduction to a volume of papers describing fisheries in the region, with the goal of making the information available to scientists and the general public. A great deal remains to be learned about the dynamics of these fisheries as well as the associated issues in biological research, fisheries management, and environmental protection.

The objective of this volume is to describe our current knowledge on the varied fisheries of Hawaii and the U.S.-associated islands of the Pacific. This introductory paper provides some general background on fisheries in the region.

Diversity of Fisheries

In the U.S. insular Pacific, the combination of highly complex habitats, high species diversity, and both native and newly introduced cultural practices leads to a diversity of fisheries unparalleled in most other parts of the U.S. Many fisheries are unique to certain localities, such as that for palolo worm in American Samoa (Craig et. al., 1993), seasonal juvenile fisheries for rabbitfish in Guam (Hensley and Sherwood, 1993), and limpet, or opihi fisheries in Hawaii (Smith, 1993). Others are common to all islands, such as the seasonal fisheries for juvenile bigeye scad in all areas. The adults of these coastal pelagics, known as akule in Hawaii or atule in American Samoa, represent the largest volume fishery in nearshore waters but are poorly known in terms of their resource potential. Nearshore reef resources are often overexploited in populated areas, a problem perhaps characteristic of tropical reef fisheries in general (Ferry and Kohler, 1987).

Evolution of Fisheries

With increasing population, changing cultural composition, and advancing technology, island fisheries have changed in many ways. Prior to western colonization, indigenous peoples of the islands depended on the marine environment and had developed a unique knowledge of marine resources and varied approaches to conservation and management. The cultural impacts of colonization of the islands by non-indigenous peoples had marked effects and typically led to the decline of traditional conservation measures (Johannes, 1978); a concise description of how this happened in Belau, in the Western Caroline Islands, is provided by Johannes (1981). In Guam, Spanish persecution of Chammorros led to the demise of the traditional fishing methods in the mid-1500's (Hensley and Sherwood, 1993). Similarly, in Hawaii, it led to the decline of the traditional management regime of the native Hawaiians that had long protected nearshore resources (Smith, 1993). Trends in the fisheries of Hawaii are perhaps the most pertinent to examine, for the greatest changes have occurred there and these may serve as a warning of what may come in the other island areas as populations increase there as well.

Temporal trends of fisheries differ markedly. Shomura[1] described the differences in fisheries of Hawaii between 1900 and 1986, the early period based upon a comprehensive data collection scheme and subsequent analysis by Cobb (1902) and the later period upon State of Hawaii commercial fishery data collection systems. While the two data sets are not identical in coverage, they provide useful comparisons. The total catch nearly doubled in the period considered. Shomura[1] noted several important trends related to the distance of the fishery from shore. Catch of coastal species declined by about 80%, while those of neritic-pelagics (akule, opelu) declined by 40%. Catch of slope and seamount species increased by 80%, whereas many-fold increases in offshore pelagics catch were evident.

It is likely that the decline of nearshore fisheries is based largely upon two factors. First, increasing population and improved fishing technology led to overfishing in the absence of effective management and regulations. Gillnet use, for example, is largely unrestricted, and this can have negative impacts on coral reef fish populations (Gobert, 1992). Similar concerns are expressed about this gear in Guam (Hensley and Sherwood, 1993). Second, habitat destruction from coastal development leads to a decline in availability and quality of critical habitat area needed to support the reef populations. This was most evident for species utilizing fishponds, a habitat which may be similar to estuaries for enhancing juvenile fish production. The decline of the numbers and function of fishponds in Hawaii has been dramatic. Cobb (1902) documented the use of fishponds in his survey of fisheries of Hawaii and even then noted a marked decline in the numbers of functioning fishponds. While the reasons may differ, declining nearshore catches in American Samoa over the last two decades (Craig et al., 1993) are also a concern.

Significant growth in several fishery sectors of Hawaii has been based upon improved technology and an expanded potential geographic range of fishing. The combination of increased catch and targeted high-value markets led to a doubling of the ex-vessel value of Hawaii fisheries from 1970 to 1990 (Pooley, 1993a). Insular fisheries moved to increasingly deeper water, and technology allowed the expansion of the slope fishery in the main Hawaiian islands during the middle of this century. As these fisheries approached full exploitation, the resource potential of the NWHI was examined by the National Marine Fisheries Service, the State of Hawaii, and the U.S. Fish and Wildlife Service in the tripartite Northwestern Hawaiian Islands Investigation in the mid 1970's to early 1980's. This program increased knowledge of resource potential (Uchida and Uchiyama, 1986) and ultimately led to a geographic expansion of the lobster and bottomfish fisheries to the NWHI (Polovina, 1993; Haight et al., 1993), providing a marked expansion of exploitable biomass. Within the NWHI lobster fishery, changing gear from wire to plastic traps led to significant catch of slipper lobster, which had been essentially unexploited with wire traps. As these resources become fully exploited, however, the available habitat for further expansion of insular fisheries in Hawaii declined markedly.

The pelagic fisheries sector has seen the most dramatic fluctuation in Hawaii. Improvement of vessel technology increased the range of the local trolling and handline fleet while other factors led to the near-demise of the skipjack pole-and-line ("aku") fleet; with the closure of the only cannery on Oahu, recent aku catches are nearly an order of magnitude below the historical peak (Boggs and Kikkawa, 1993). A general trend away from "bulk fisheries" for pelagics (e.g. fishcake, canned tuna) and development of "quality," high price products (e.g. sashimi tuna, transshipped products) has enhanced the market value of Hawaii's pelagic fisheries (Pooley, 1993b). Even so, continuing improvements in technology have led to substantial expansion of the longline fishery and more directed targeting for bigeye tuna and broadbill swordfish fishery during the late 1980's (Boggs and Ito, 1993).

Management Issues

With the decline of traditional management approaches, increasing population, and development of new fisheries, declines in nearshore stocks were inevitable (Shomura[1]; Hensley and Sherwood, 1993). As offshore fisheries grew, allocation conflicts have developed (Boggs and Ito, 1993). With the passage of the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA) and establishment of the regional fishery management councils, federal jurisdiction was established and in some cases established regulations that superseded state or territory regulations. As the Western Pacific Regional Fishery Management Council (WPRFMC) began to develop fishery management plans (FMP's), the lack of adequate fisheries data became evident. Although time series of fisheries catch information were available in the state of Hawaii, questions existed about the quality and consistency of these data for rigorous analysis (Smith, 1993). Data for Hawaii's recreational fisheries, which may represent a large portion of harvest in the nearshore areas, are virtually unrecorded. In Guam, American Samoa, and CNMI, however, de novo development of the WPACFIN system began consistent time series of fisheries data (Hamm, 1993).

Management mechanisms have evolved in Hawaii to reduce fishing effort in the commercial fisheries, including limited entry (bottomfish, lobster), moratoria on new entrants to the fishery (longlining), closed seasons and quota (lobster), and area closures (longlining). Nearshore areas in Hawaii have received limited protection through Marine Life Conservation Districts (MLCD's), a progressive approach taken by the Division of Aquatic Resources (Smith, 1993). Such closed

[1] R. S. Shomura. 1987. Hawaii's marine fishery resources: Yesterday (1900) and today (1986). Honolulu Lab., Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Southwest Fish. Cent. Admin. Rep. H-87-21, 25 p.

areas for fishery management purposes represent an alternative that is consistent with interest in marine refuges and sanctuaries, and a theoretical basis for such management is developing (DeMartini, 1993). Closed areas have also been used for special purposes, such as creating areas for nonconsumptive use of marine resources (a function served by many Hawaii MLCD's) or for protection of sensitive areas. An example of the latter is protection of the Hawaiian monk seal in the NWHI (Nitta and Henderson, 1993). Lobster fishing is prohibited inside 10 fm in the NWHI owing to designation of critical habitat for the monk seal, and longlining is prohibited within 50 n.mi. of the NWHI owing to fishery interactions.

Interactions among different scales of fisheries and the differing agencies responsible for their management present a challenge in many areas. In the nearshore, non-selective gears like gillnets and lack of data on their catch make specific management measures difficult and contribute to stock declines. Moving offshore, many stocks, such as bottomfish, fall within the jurisdiction of both state (or territory) and federal management prerogatives; this problem is presently being faced with bottomfish management in the main Hawaiian Islands. For pelagics, even though all species are now under the MFCMA, fluctuations in catch rates of many species mimic many of the changes in Pacific-wide stocks, suggesting that local fluctuations are in concert with the wider Pacific stocks, and that local effects often change with environmental variation. Unfortunately, the wider ranging stocks lack the scientific basis and institutional structures needed for management (see Doulman, 1987).

Environmental Issues

Improved awareness of environmental issues in the marine environment is evident in the general public, and Hawaii and the Pacific islands are no exception. Land-based development associated with increasing population in island ecosystems is a serious concern owing to degradation of nearshore habitats (Boehlert et al.[2]; Baines and Morrison, 1990). Examples of problems include point and nonpoint source pollution, coastal landfills, diversion of freshwater from former estuarine areas or fishponds, dredging and siltation impacts on corals, and algal blooms. While such problems may not be evident in all these island areas, their relationship to human population pressure is well documented.

Fishing can itself impact the environment; destructive fishing practices (bleach, dynamite, or nonselective gears) have a long history in island areas, but public awareness has led to regulations banning or controlling them. Set gillnet fishing is increasingly viewed as a nonselective method with relatively high bycatch of unintended species, similar to driftnet fisheries. In Hawaii, however, bills to regulate set gillnets have routinely been killed politically, although a recent (1992) resolution calling for studies to improve regulations was passed.

Impacts of fishing on protected species is also a point of environmental concern. Examples in local fisheries include gillnet impacts on turtle, and longline takes of turtles, monk seal, and seabirds (Nitta and Henderson, 1993).

Fishing may also have impacts on biological diversity. Fishing only selected species in the high diversity ecosystems characterizing these areas may lead to species replacement, and the new dominant species may be smaller and less useful for human consumption (Jones, 1982). While concrete documentation of such species replacement is not evident in Hawaii and the U.S. insular Pacific fisheries, experimental fishing on patch reefs at Midway did change community structure and the abundance of certain prey species (Schroeder, 1989). A more dramatic example is provided by the trawl fishery in the Gulf of Thailand, where the dominant fish and large invertebrate species decreased to less than one-fifth of their original abundance (as reflected in catch rate), and the squid *Loligo* spp. became the clear dominant, with perhaps a ten-fold increase in abundance (Longhurst and Pauly, 1987). Multispecies management models for tropical fisheries are not sufficiently well developed to predict these kind of changes (Sainsbury, 1982).

[2]G. W. Boehlert, P. L. Jokiel, and D. J. Mackett. 1985. Issues in fisheries habitat conservation and research for the Hawaiian archipelago and Central Pacific. Honolulu Lab., Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Southwest Fish. Cent. Admin. Rep. H-85-10, 39 p.

Concluding Remarks

The papers in this volume document the development of this region's fisheries and indicate the scope of research that has been conducted by many agencies; still, it is clear that much remains to be learned. This is also true for the fisheries management and environmental protection issues as for the basic biological and environmental research required to understand the physical processes at work in these diverse island habitats. For successful fisheries management, however, it is critical to appreciate the human diversity of these island areas; this requires a deeper understanding of the social processes which affect the ability of government to work with the community on common solutions to fishery management problems. I hope that this volume contributes the basic background information which can place the search for such solutions on a firmer scientific footing.

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Hawaii's Marine Fisheries: Some History, Long-term Trends, and Recent Developments

SAMUEL G. POOLEY

Introduction

Recently Hawaii's commercial marine fishery has experienced a period of rapid growth and structural change, and its characteristics are quite different from what they were a decade ago. Some of these changes are the result of governmental and private-sector decisions on fishery development in Hawaii, but many have occurred because of increasingly competitive pressures, particularly as they have affected mainland U.S. commercial fishing fleets. Further changes are anticipated as diverse fishing interests (including both large-scale and small-scale commercial, indigenous, and recreational fishing interests, as well as nonconsumptive marine resource interests) are worked out in fishery, marine, and

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ABSTRACT — This paper provides an overview of Hawaii's marine fisheries from 1948 to the present. After three decades of decline following a brief period of growth at the conclusion to World War II, Hawaii's commercial fisheries began a decade of sustained development in the 1980's. At the same time, fisheries management issues became more significant as different segments of the fishery came into more direct competition. This paper provides new estimates of commercial landings for the 1977–90 period, and summarizes limited information on recreational and subsistence fisheries in the 1980's. It also provides some historical context which may be useful in evaluating fishery development and management options.

coastal zone management processes. This paper concentrates on the economic development of the offshore commercial fishery, and places somewhat greater emphasis on the large-scale fisheries. Biological and management features of Hawaii's marine fisheries are considered in other papers in this number (Mar. Fish. Rev. 55(2)).

Hawaii's marine fisheries can be divided into three geographical areas (Fig. 1):

1) The inhabited main Hawaiian Islands (MHI), with their surrounding reefs and offshore banks (the island of Hawaii to Niihau and Kauai);

2) The Northwestern Hawaiian Islands (NWHI), a 1,200 mile string of basically uninhabited reefs, shoals, and islets ranging west northwest from the main Hawaiian Islands (i.e., west of Niihau and Kauai);

3) The mid-North Pacific Ocean, ranging from lat. 40°N to the Equator, and from long. 145°W to long. 175°E.

Hawaii's fishing fleets can also be divided into three somewhat overlapping or interconnected segments:

1) Large-scale commercial fishing.

Although termed "large-scale" in Hawaii, by mainland U.S. and foreign fishing fleet standards almost all the vessels in this segment would be considered small. Most "large-scale" commercial fishing vessels in Hawaii are less than 100 feet in overall length. These include the older aku boats (pole-and-line sampans[1] fishing for skipjack tuna[2]) (Table 1) and tuna longline sampans (also wooden but of a different design), as well as modern tuna and swordfish longline vessels, distant-wa-

Table 1.—List of common and scientific names of frequently caught commercial species in Hawaii.

Common name	Scientific name
Bottomfish	
Snappers	
Onaga	*Etelis coruscans*
Opakapaka	*Pristipomoides filamentosus*
Ehu	*E. carbunculus*
Kalekale	*P. seiboldii*
Gindai	*P. zonatus*
Uku	*Aprion virescens*
Lehi	*Aphareus rutilans*
Yellowtail kalekale	*P. auricilla*
Taape	*Lutjanus kasmira*
Grouper	
Hapuupuu	*Epinephelus quernus*
Jacks	
White ulua	*Caranx ignobilis*
Black ulua	*C. lugubris*
Butaguchi	*Pseudocaranx dentex*
Kahala	*Seriola dumerili*
Other	
Lobster	
Spiny	*Panulirus marginatus*
Slipper	*Scyllarides squammosus*
Pelagic Management Unit Species	
Blue marlin	*Makaira mazara*
Striped marlin	*Tetrapturus audax*
Broadbill swordfish	*Xiphias gladius*
Shortbill spearfish	*T. angustirostris*
Black marlin	*M. indica*
Indo-Pacific sailfish	*Istiophorus platypterus*
Mahimahi	*Coryphaena hippurus*
Ono (wahoo)	*Acanthocybium solandri*
Blue shark	*Prionace glauca*
Mako shark (short-fin)	*Isurus oxyrinchus*
Mako shark (long-fin)	*I. paucus*
Oceanic whitetip shark	*Carcharhinus longimanus*
Thresher shark	*Alopias superciliosus*
Tiger shark	*Galeocerdo cuvieri*
Tunas	
Bigeye Tuna	*Thunnus obesus*
Yellowfin tuna	*T. albacares*
Albacore	*T. alalunga*
Skipjack tuna (Aku)	*Katsuwonus pelamis*
Kawakawa	*Euthynnus affinis*
Frigate tunas	*Auxis* spp.

[1]The term "sampan" in Hawaii refers primarily to wooden-hulled fishing craft of a design introduced by Japanese fishermen in the early 1900's. The vessels range from 35 to 75 feet with a flared bow, a low stern, and a deep profile to maintain seaworthiness in Hawaii's rough waters.

[2]Hawaii common names for commercial marine fish and shellfish species are used throughout this paper. Scientific names and corresponding Hawaii, names are found in Table 1.

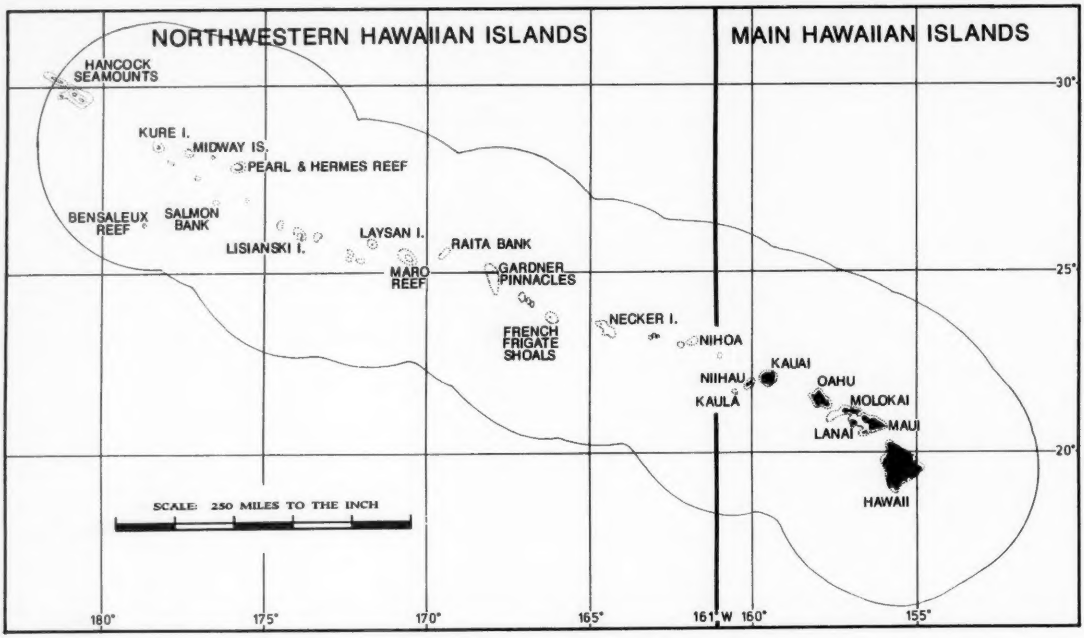

Figure 1.—Hawaii map, including NWHI.

ter albacore trollers, and multipurpose vessels which fish for bottomfish (deepwater snappers, groupers, and jacks) and spiny and slipper lobster in the NWHI. These vessels can operate as far as 1,000 nautical miles from Hawaii throughout the mid-North Pacific, and some span the South Pacific. Most operate within 200 miles of the MHI or within the NWHI.

2) Small-scale commercial fishing.

The vessels in this segment include a wide variety of trailered and moored boats between 12 and 45 feet in length. These vessels primarily use trolling and handline techniques, although some traps and surrounding nets are used. The target species include tunas, billfish, mahimahi, ono (wahoo), bottomfish for the trollers and handliners; bottomfish, reef fish, and crustaceans for the trap vessels; and small midwater scads (known locally as akule and opelu) for the surrounding-net fishery. These vessels operate almost exclusively in the MHI.

3) Small-scale recreational, part-time commercial, and subsistence fishing.

This segment includes the same kind of vessels as found in the small-scale commercial fleet, as well as some very small boats (including surf boards and sail boards), charter fishing boats and dive fishing boats. Although charter fishing is a commercial operation, its clients are oriented toward recreational opportunities and thus it is distinguished from commercial fishing. The target species for this segment of the fishery are more varied than those of the commercial segments, and include a variety of reef species, as well as the more familiar tunas, billfish, mahimahi and ono (wahoo), bottomfish, and crustaceans. The fishing methods used are also considerably more varied.

The issue of categorizing Hawaii's small-boat fisheries is a difficult one, and is discussed later in this paper. For the moment we would categorize this segment as one where the fishery has limited fishing power and its fishermen have mixed motivations in terms of fishing activity.

Hawaii's Traditional Commercial Marine Fisheries

Shortly after Statehood, a U.S. Department of Interior, Bureau of Commercial Fisheries proposal labeled the Hawaii fishery as "dying" (Iversen[3]). Hawaii's major commercial fisheries had been dominated by traditional practices that reflected Hawaii's Japanese immigrant heritage and its impact on the local fishery and seafood markets. The predominant commercial fishery was aku (skipjack tuna), which was caught by a live-bait, pole-and-line, wooden sampan fleet, known as aku boats (Fig. 2), and which was landed primarily for canning. In 1960, over 60% of Hawaii's total recorded commercial fishery landings (by weight) was aku, and the percentage remained over 50% until 1970.

By the mid-1970's the number of aku boats and their companion sam-

[3]R. T. B. Iversen, 45-626 Halekou Place, Kaneohe, HI 96744. Personal commun., 1991.

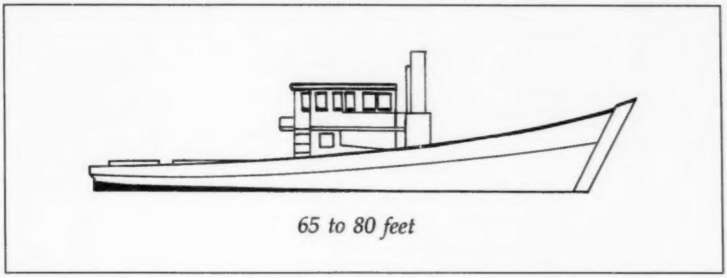

Figure 2.—Drawing of typical Hawaii aku (skipjack tuna pole-and-line) boat.

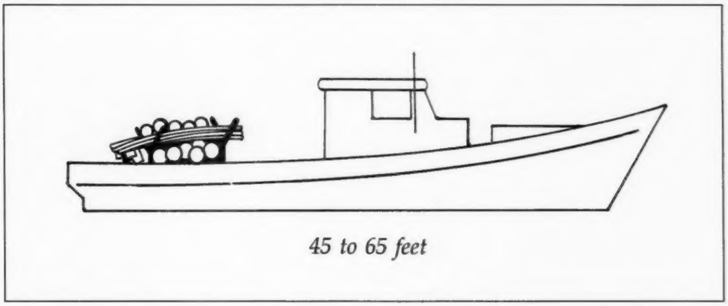

Figure 3.—Drawing of typical Hawaii flagline (longline sampan) boat.

Table 2.—Hawaii commercial fisheries, 1990. NMFS estimates based on logbooks and shoreside monitoring. MHI = main Hawaiian Islands; NWHI = Northwestern Hawaiian Islands.

Fleet	Weight (1,000 lb.) Caught	Weight (1,000 lb.) Sold	Thousand dollars
Longline	13,090	12,200	$28,800
Troll and handline pelagics	4,460	4,050	6,980
Aku boat	1,005	1,005	1,838
MHI bottomfish	830	810	3,300
NWHI bottomfish	420	400	1,070
NWHI lobster	949	949	4,887
Other	1,700	1,594	3,513
Total	22,454	21,008	50,388

pans, the longline tuna boats (known locally as flagline boats, Fig. 3), had decreased substantially, and the condition of many of the boats was poor. Fishing remained close to the main Hawaiian islands, although some older bottomfish boats fished the NWHI. Volume of fish in the fresh fish market had declined, and few improvements in marketing were apparent. Most fresh seafood appeared to be consumed in the home, and ethnic identification with particular species was very strong. Nearshore reef and schooling fish were still relatively abundant, but Hawaii's commercial fishery reached its nadir in 1975.[4]

Figures 4 and 5 provide estimates of Hawaii's long-term commercial fishing landings and revenue.[5] Revenues throughout this paper are inflation-adjusted values to a 1990 base year. Figures on landings and revenue for the period 1948–76 are based entirely on the Hawaii Division of Aquatic Resources (HDAR) commercial fishing landings reports. Figures for the period 1986–90 are based largely on NMFS estimates of Hawaii's commercial landings and on our own wholesale market monitoring program. The period 1977–85 is a combination of the HDAR data with NMFS estimates of particular gear types (longline and NWHI lobster).[6] Table 2 provides a breakdown of the NMFS data for 1990 by gear type.

Figure 4 differentiates the aku boat fishery (skipjack tuna) from the rest of the fishery (identified as "non-aku") because the aku fleet has been the source of most annual variation in landings. The average annual variation in detrended aku landings was 164% (compared with 27% for non-aku landings) in the period 1948–90.[7] Any analysis of the overall Hawaii commercial fishery over time must differentiate the overall trend from these fluctuations in the aku fishery.

Aku landings declined through the mid-1970's to the closing of the cannery in 1984, and then continued to fall through 1990. Aku landings fell as a percentage of total landings (by weight) from over 70% in the 1960's to less than 20% in the last five years of the 1980's, and to only 4.5% in 1990. However aku revenue has not fallen as appreciably because of the higher market price of fresh aku (compared with the cannery price in the pre-1985 period).

Major Developments Since the Mid-1970's

The nature and value of Hawaii's present day fisheries and seafood industry have changed dramatically since the 1970's. The commercial fishery has more than doubled in inflation-adjusted ex-vessel value since 1970 to $50 million in 1990 and $60 million in 1991. The seafood market is probably worth over $100 million (including imported seafood), there is a $10-15 million char-

[4]In terms of inflation-adjusted revenue. The lowest landings were in 1969 using NMFS estimates, but 1975 was the second lowest year.

[5]Estimates are required because official records of commercial fisheries landings were not comprehensive in some years during that period.

[6]Appendix A, available from the author, provides additional detail on the NMFS estimates for the period 1979-90, as well as time-series for individual gear types (aku boat, longline, NWHI lobster, NWHI bottomfish, main Hawaiian Islands, and other gears) from 1948 to 90.

[7]Detrending is a simple statistical procedure to remove the long-term change (growth or decline) in a time series. The resulting figures then reflect more accurately the shorter-term variation, in this case, the year-to-year variation, in the 1948 to 1990 time period.

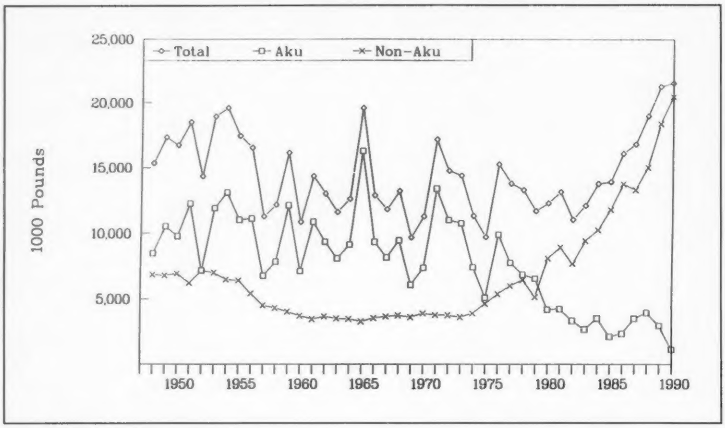

Figure 4.—Hawaii commercial fishery landings (pounds), 1948-90. NMFS estimates, total, aku (skipjack tuna), and all other species.

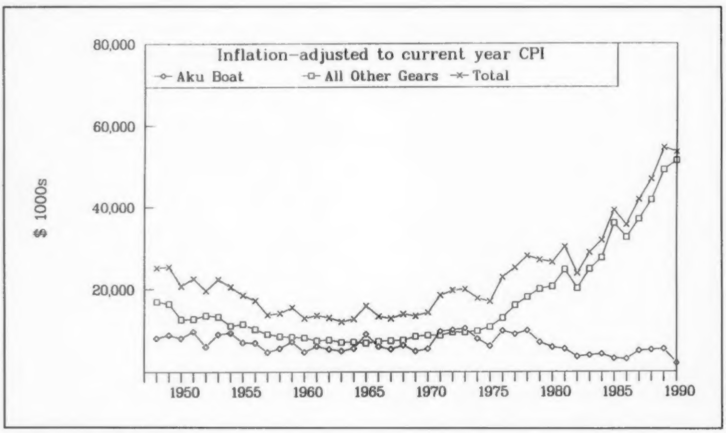

Figure 5.—Hawaii commercial fishery revenue, 1948-90. NMFS estimates, total, aku boat (pole-n-line skipjack tuna), and all other gears. Revenue adjusted for inflation to 1990 U.S. $ base.

ter boat industry, probably an equivalently valued tournament fishery, and there is a recreational and subsistence marine fishery with direct expenditures of $24 million.[8] Figure 6 displays our estimate of the Hawaii seafood market supply in 1990, with 20 million pounds ($50 million) from commercial fishing, 9 million pounds from recreational fishing, 15 million pounds ($30 million) from foreign imports, 24 million pounds ($45 million) from the mainland U.S., and 3.5 million pounds ($10 million) exported.[9]

Perhaps the most notable long-term trend in Hawaii's overall commercial fishery is the dramatic increase in inflation-adjusted ex-vessel revenue in the 1980's (Fig. 5). The increase in revenue (240%), which is reflected in the increased value of the marketing sector, is even greater than the increase in pounds landed (200%), although less than the increase in non-aku landings (300%). The increase in average aggregate price reflects a substantially growing demand, particularly in the restaurant and export (U.S. mainland and foreign) markets, more than matching the increased supply for most species during the period.

There are many elements to these recent changes in Hawaii's seafood industry. Perhaps the first harbinger of change was the arrival of albacore trollers from the west coast en route to newly discovered fishing grounds north of Midway Islands late in the 1970's. This caused a new perspective on the nature of Hawaii's role in the Pacific-wide fishery and led to some substantial changes on the Honolulu waterfront. Not the least of these changes was the technological demonstration effect of the mere presence of these distant-water, highly mobile vessels[10]. In 1985, there were 75 albacore trollers in the U.S. North Pacific fishery (Hawaii Division of Aquatic Resources, 1986). Landings peaked at 3.8 million pounds, but because of logistics, the closure of the Honolulu cannery, and the changing world tuna market, Hawaii did not become the tuna processing and transshipment center that was anticipated. Eventually less than 20 albacore vessels chose to make Honolulu their home port.

Also in the 1980's, the Northwestern Hawaiian Islands spiny lobster fishery began to bloom. The NWHI possess a large EEZ but have relatively limited fishing grounds for nonpelagic species. During a cooperative research effort of the NMFS, HDAR, University of Hawaii, and U.S. Fish and Wildlife Service in the 1970's (Grigg and Tanoue,

[8]The definition and determination of "value" for recreational and subsistence fisheries is a complex methodological issue. Direct comparison of the expressed dollar values of commercial vs. recreational fisheries is generally not appropriate; see Edwards (1990) for a primer on these issues. Meyer (footnote 20) estimated the nonmarket value of small-boat noncommercial fishing in Hawaii at $200 million, using hedonic valuation methods, compared to actual direct expenditures of $24 million.

[9]Hawaii's seafood marketing sector is described in: J. C. Cooper and S. G. Pooley. 1982. Total seafood volume in Hawaii's wholesale fish markets. Southwest Fish. Cent. Admin. Rep. H-82-15, 12 p.; J. C. Cooper and S. G. Pooley. 1983. Characteristics of Hawaii's wholesale seafood market. Southwest Fish. Cent. Admin. Rep. H-83-22, 33 p.; W. K. Higuchi and S. G. Pooley. 1985. Hawaii's retail seafood volume. Southwest Fish. Cent. Admin. Rep. H-85-06, 16 p.; and MacDonald and Deese (1988).

[10]The demonstration effect relects indirect learning initiated by the presence of a new technology or methodology, usually introduced into a culture or a society from outside.

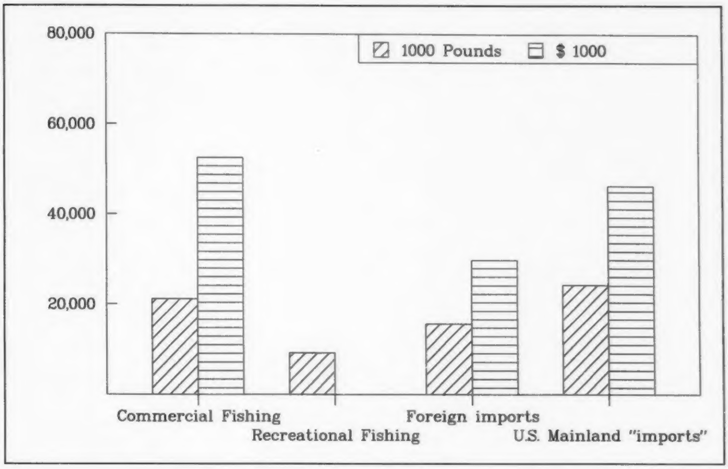

Figure 6.—Hawaii seafood market shares, 1990. NMFS estimates.

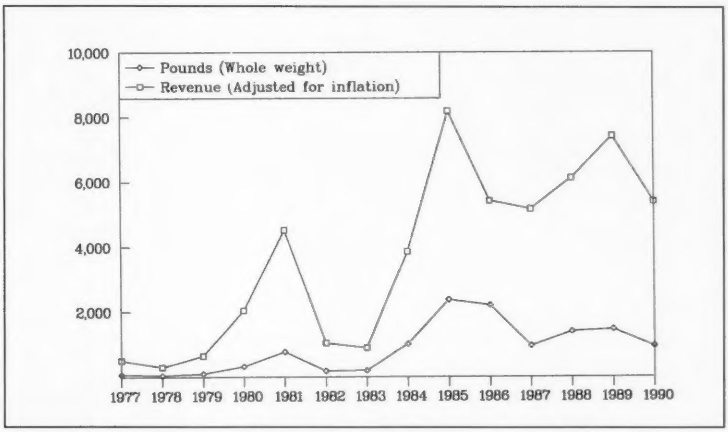

Figure 7.—NWHI lobster landings, pounds and revenue, 1977-90. NMFS estimates and figures. Revenue adjusted for inflation to 1990 U.S. $ base.

1984), scientists discovered substantial quantities of spiny lobster in the NWHI. By the mid-1980's, with the additional discovery of slipper lobster, NWHI lobster was one of Hawaii's largest fisheries in terms of ex-vessel revenue (Fig. 7). To develop the lobster fishery, new fishermen and new boats came to Hawaii, primarily from the Pacific Northwest (Fig. 8). Large vessels, some over 100 feet in length, with advanced technology freezing and processing equipment, entered the fishery. New traps were introduced from California which made fishing not only more efficient but also allowed the slipper lobster to be caught commercially.

Although the first lobsters were sold locally as a live product, soon almost all were produced as a frozen tail product and sold to mainland U.S. buyers. This was the first premium product of Hawaii's new commercial fisheries, with prices ranging up to $13.50 per pound for the tails. However, neither the albacore nor the lobster fishery changed the basic structure of the Hawaii fresh fish market.

The NWHI also proved to be a good location for bottom fishing (mechanized "handline" fishing for snappers, groupers, and jacks), which required a medium-scale modern fishing vessel (Fig. 9) similar to those used in the lobster and albacore fisheries. The expanding supply of pink and red snappers (opakapaka and onaga) locally made possible the expansion of the restaurant market by allowing a regular and consistent supply of relatively fresh fish (Fig. 10). At the same time, the restaurant market for fresh mahimahi also expanded, providing a new source of income for local trollers (Takenaka et al.[11]). Local wholesale dealers were able to promote fresh local mahimahi as a substitute for some of the large imports of frozen mahimahi. Since both bottom fish and mahimahi were landed fresh and sold primarily at the Honolulu auction, this marked an important change in the local fishery and reinvigorated the local fresh fish market.

With a much larger restaurant market in Honolulu, bottomfish fishermen from the main Hawaiian Islands were able to obtain premium prices for their considerably fresher catch, and thus were motivated to increase their landings (Fig. 11). Finally, some wholesale seafood dealers began sending opakapaka and mahimahi to the mainland, establishing a distinctively Hawaiian seafood presence linked to Hawaii's tourism market.

In the late 1970's and early 1980's the traditional Hawaiian tuna handline fisheries, known as ika shibi (Ikehara[12]) and palu ahi, revived owing to fuel-efficient small-scale vessels (Fig. 12). These fisheries, which targeted yellowfin and bigeye tuna (both known locally as ahi, along with albacore), were centered on the Big Island (Hawaii), but much of the product at the time was shipped to Honolulu for the restaurant market. This was a useful de-

[11]B. Takenaka, L. Toricer, S. G. Pooley, and J. C. Cooper. 1984. Recent trends in the commercial fishery and marketing of mahimahi and ono in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-84-9, 20 p.

[12]W. Ikehara. 1981. A survey of the ika-shibi fishery in the state of Hawaii, 1980. U.S. Dep. Commer., NOAA, Natl. Mar.Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin Rep. H-82-4C, 11 p.

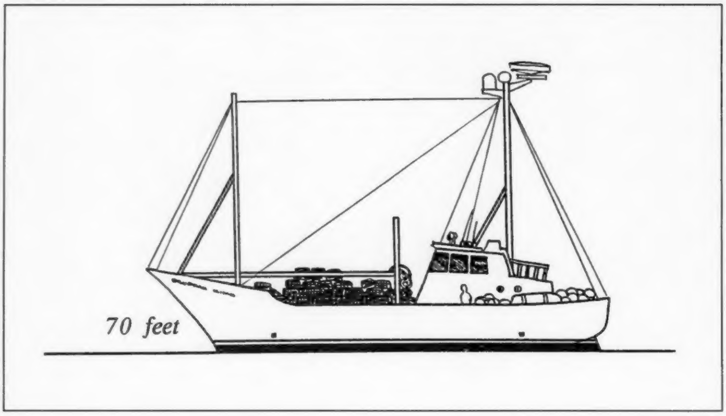

Figure 8.—Drawing of typical NWHI lobster boat.

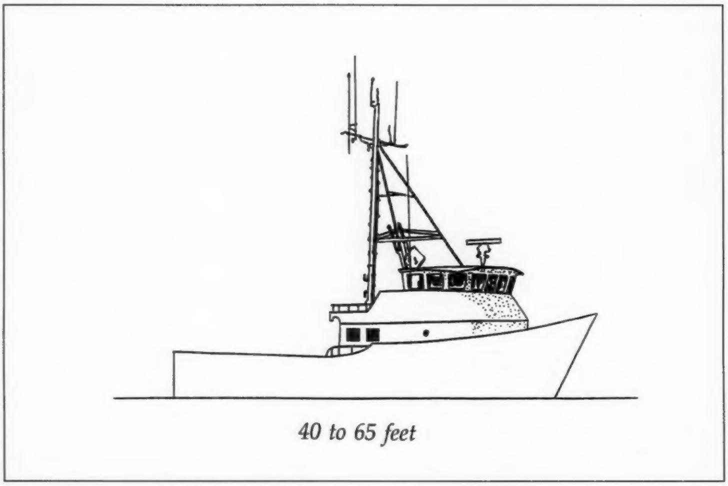

Figure 9.—Drawing of typical NWHI bottomfish boat.

velopment for the neighbor islands whose commercial fishery appeared to be left behind by the growth of the large-scale fishing fleets based in Honolulu. Today, there are strong local markets for fresh fish on the neighbor islands, associated with the expansion of the tourist trade on those islands, and there is considerable "export" of fresh fish to the U.S. mainland. However, access by handline boats to the higher value-added market has been limited on account of a phenomenon known as the "burnt tuna phenomenon," a condition in which the meat of handline and troll caught yellowfin tuna is metabolically degraded during fishing when not offset by rapid icing. Nonetheless, landings of tuna and other pelagics (primarily billfish, mahimahi, and ono) by troll, handline, and miscellaneous gears (i.e., excluding longline and aku boat) increased by elevenfold from 1970 to 1990 (Fig. 13).

In 1984 the tuna cannery Hawaiian Tuna Packers closed, coinciding with a period of substantial reorganization in the multinational canned tuna industry. As a result, the aku boat fleet declined from 12 active boats in 1979 (Hudgins, 1980) to just 7 active boats in 1986, selling solely to the fresh market (Boggs and Pooley, 1987; Pooley et al.[13]). Attempting to expand that market was a major project of State government in the 1980's (MacDonald et al., 1991), but current conditions in the fishery suggest that an entirely new start will be required, including a solution to the perceived bait problem and limitations on market penetration (primarily due to limited shelf life), if the potential yield of the skipjack resource is to be achieved in the future (Boggs and Pooley, 1987). Landings in the past five years have averaged less than 5 million pounds, with only 4 full-time aku boats active in the fishery.

By the mid-1980's, the export market for Hawaii's fresh bigeye tuna rose dramatically, largely as a result of marketing efforts by major wholesale dealers and the favorable exchange rate between the dollar and the yen. This marked the early resurgence of Hawaii's traditional longline tuna fleet, which produces a superior-grade tuna for sashimi (raw tuna). In the late 1980's, both NWHI bottomfish and lobster boats began facing lower catch rates and increased regulation, so that a number of these vessels began to transfer to the longline fishery.

In the early 1980's, perhaps as few as 15 vessels were fishing with longline gear in Hawaii. Today, over 150 vessels are in the longline fleet. Most of the vessels are newer and larger. Whereas the older sampans are about 45 feet, the new steel-hulled vessels range from 65 to 115 feet (Fig. 14). Many of the older vessels have new owners and have been refurbished. The longline crews have been trying a number of different fishing strategies, from fishing as far as 1,200 miles from Honolulu to fishing right off the reef,[14]

[13]S. G. Pooley, S. Teramoto, and A. C. Todoki. 1988. Hawaii's aku fishery in 1986 and 1987. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent. Admin. Rep. H-88-16, 15 p.

[14]Fishing off the reef provides a major fisheries management controversy. The Western Pacific Fishery Management Council has closed the waters around the main Hawaiian Islands to

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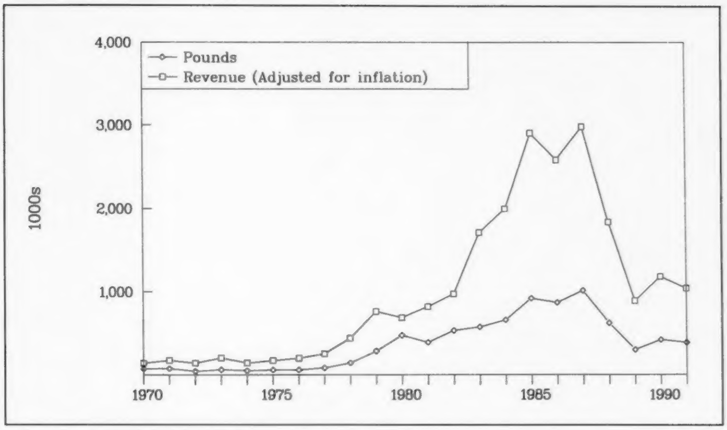

Figure 10.—NWHI bottomfish landings, pounds and revenue, 1970-91. NMFS estimates. Revenue adjusted for inflation to 1990 U.S. $ base.

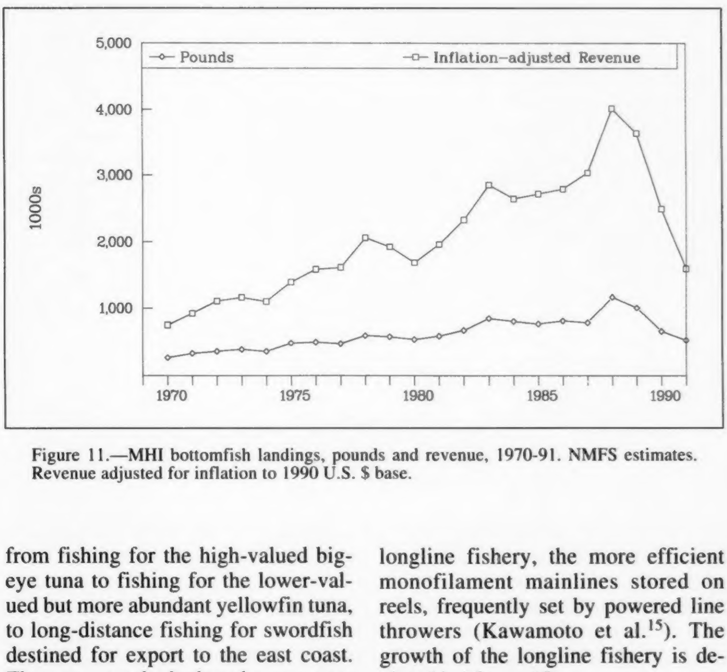

Figure 11.—MHI bottomfish landings, pounds and revenue, 1970-91. NMFS estimates. Revenue adjusted for inflation to 1990 U.S. $ base.

from fishing for the high-valued bigeye tuna to fishing for the lower-valued but more abundant yellowfin tuna, to long-distance fishing for swordfish destined for export to the east coast. The new vessels deployed a new gear which has now become the predominant gear throughout the Hawaiian longline fishery, the more efficient monofilament mainlines stored on reels, frequently set by powered line throwers (Kawamoto et al.[15]). The growth of the longline fishery is depicted in Figure 15.

Hawaii's market for fresh tuna (and other pelagics such as mahimahi) is now highly competitive, with competition in supply from Florida to Australia. The local fish market must now compete with the Tskuji market in Tokyo for the raw product, and local consumers must compete with the local restaurant trade and the export market.

If we take a brief look in retrospect, in 1979 the Hawaii Fisheries Development Plan predicted commercial fisheries growth to 50 million pounds in 1990 and 85 million pounds in the year 2000 (Department of Land and Natural Resources, 1979b). As one of the Plan's co-authors, I would say we failed to anticipate the likelihood and potential consequences of the collapse of U.S. production of canned tuna (the closure of the California and Hawaii canneries, and the emphasis on purse-seine tuna processing at the American Samoa and Puerto Rico canneries), and thus our forecasts for skipjack and albacore tuna landings were far afield. We also expected a rapid development of the oceanic shrimp fishery, but ultimately the resource did not support large-scale development (Tagami and Ralston[16]). But for ahi, NWHI lobster and bottomfish, the projections for growth have been quite reasonable. The prospects for further development in pelagics remain strong, although development must now be tempered by fisheries management considerations.[17]

Fleets and Current Landings

Hawaii's commercial fishery exceeds $50 million in ex-vessel revenues, from 22 million pounds of landings in 1990. The longline tuna

longline fishing and has imposed a moratorium on new entry into the Hawaii-based longline fishery from 1991 through 1994 (Amendments 2, 4, and 5 to the Fishery Management Plan for the Pelagic Fisheries of the Western Pacific Region, Western Pacific Regional Fishery Management Council, Honolulu, Hawaii 1986, as amended in 1991.)

[15]K. E. Kawamoto, R. Y. Ito, R. P. Clarke, and A. Chun. 1989. Status of the Hawaiian tuna longline fishery 1987-88. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-89-10, 33 p.

[16]D. T. Tagami and S. Ralston. 1988. An assessment of exploitable biomass and projection of maximum sustainable yield for *Heterocarpus laevigatus* (shrimp) in the Hawaiian Islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-88-14, 22 p.

[17]The relationship, or lack thereof, of fishery development and fishery management has been a difficult one. The Western Pacific Fishery Management Council initially tried to bridge the gap, but it had few resources which could be placed on fishery development issues. Within the State of Hawaii government, the two functions exist in different departments, while within NMFS, fishery development functions have been phased out since the late 1970's except for awards to private sector projects (the Saltonstall-Kennedy grants). Most State of Hawaii fishery

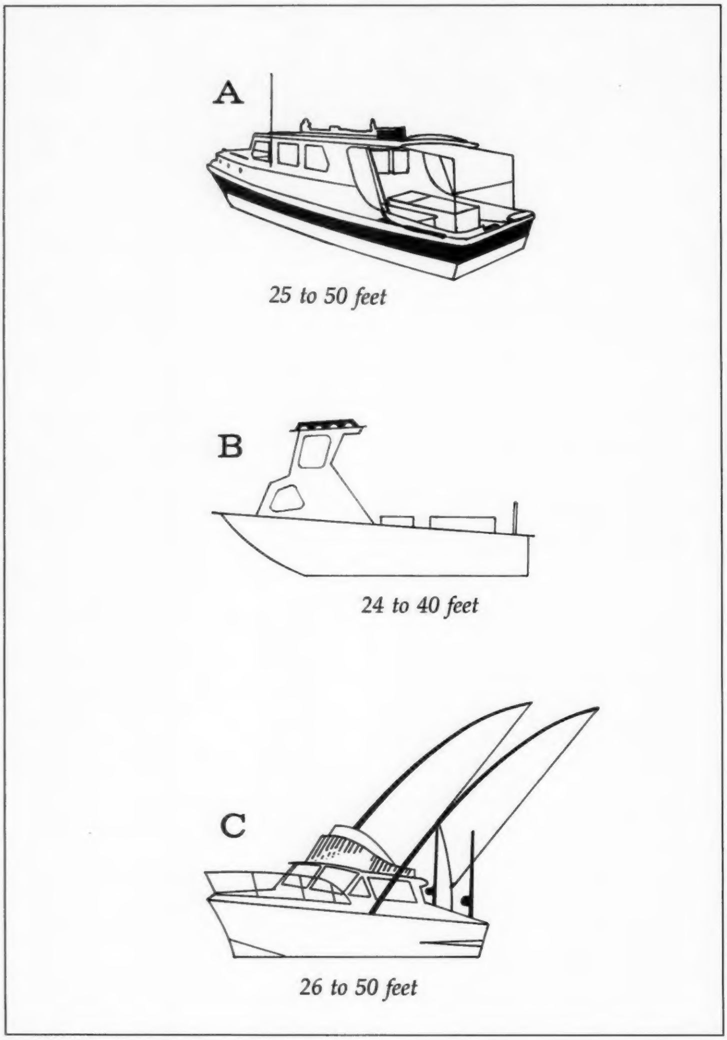

Figure 12.—Drawing of typical MHI (A) bottomfish, (B) pelagic handline, and (C) trolling boats.

fishery is the largest commercial fishery in Hawaii, valued at $29 million. The smaller-scale troll and handline fisheries for tuna and mixed pelagics, such as mahimahi, are next in value, at

Continued

[17] *Continued*
conservation activities are oriented toward nearshore fisheries. The State's 1985 fishery development plan added an emphasis toward the noncommercial sectors Hawaii's fishery and warned: "Fisheries development can only be promoted for those fishery resources that can withstand increased fishing pressure without damaging the integrity of the resource. . . ." (Hawaii Division of Aquatic Resources, 1986).

$7 million, while lobster, aku (skipjack tuna), and bottomfish (snappers, groupers, and jacks) are the other major commercial fisheries (Table 2).

While there were 15,000 boats registered (or documented) in Hawaii in the 1980's, only from 7,500 to 5,000 were used for fishing (Skillman and Louie[18], Sumida, et al.[19]; Meyer Resources Inc.[20]). Less than 2,000 vessels are presently registered for commercial fishing and, while there are less than 3,500 people holding commercial fishing licenses (issued to individuals), most commercial fishing license holders make minimal record of landings. There are perhaps only 750–500 boats that could be considered full-time commercial and charter-boat fishing operations. Almost all the fishing boats in Hawaii are less than 100 feet overall; only a portion of the longline fleet is longer than 75 feet.

This mixture of small and medium-sized fishing vessels has been relatively beneficial for Hawaii's fisheries (Pooley[21]). Large vessels can easily overharvest many of the nonpelagic resources while having a hard time making ends meet over the long run in such limited fisheries[22]. Many of the medium-sized vessels have the advanced technology and mobility to make switching between fisheries a viable business strategy[23], while at the same time not having a strongly negative impact on the small-scale commercial and recreational fishermen. Indeed, it was believed that Hawaii's offshore pelagic fisheries, which are substantially less susceptible to overfishing by small and medium-sized

[18] R. A. Skillman and D. K. H. Louie. 1984. Inventory of U.S. vessels in the central and western Pacific: Phase 2—verification and classification. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-84-12, 21 p.

[19] R. F. Sumida, B. M. Ito, and J. P. Draper. 1985. Inventory and uses of vessels in Hawaii, 1984. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., nontechnical report.

[20] Meyer Resources Inc. (P. A. Meyer.) 1987. A report on resident fishing in the Hawaiian islands. (A project to determine the economic value of recreational fishing in Hawaii.) U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-87-8C, 74 p.

[21] S. G. Pooley. 1985. The hopelessness of the invisible hand: small versus large fishing vessels in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-85-02, 16 p.

[22] For example, Clarke and Pooley (1988) found that mid-sized vessels (65 feet overall length) were the most profitable in the NWHI lobster fishery, while the larger vessels (greater than 75 feet in overall length) were not profitable. However, the larger lobster vessels have participated in the NWHI lobster fishery and have a dramatic impact on available stocks of lobsters.

[23] A strategy increasingly constrained by the implementation of limited entry in Hawaii's major commercial fisheries.

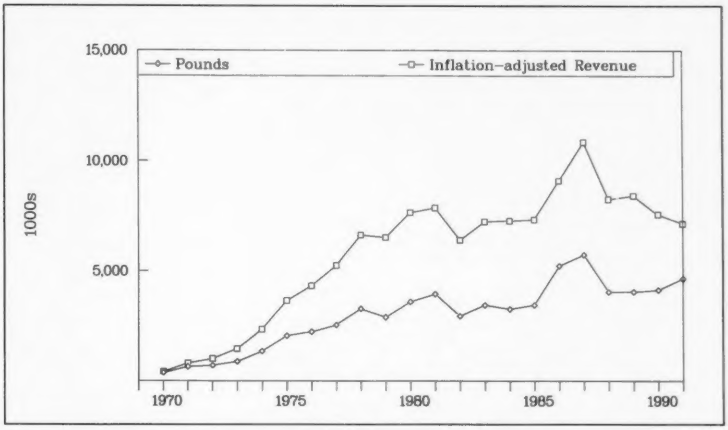

Figure 13.—MHI pelagic landings, pounds and revenue, 1970-91. NMFS estimates. Revenue adjusted for inflation to 1990 U.S. $ base.

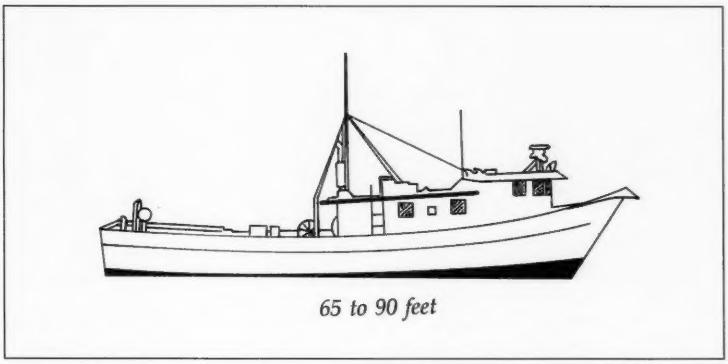

Figure 14.—Drawing of typical modern Hawaii longline boat.

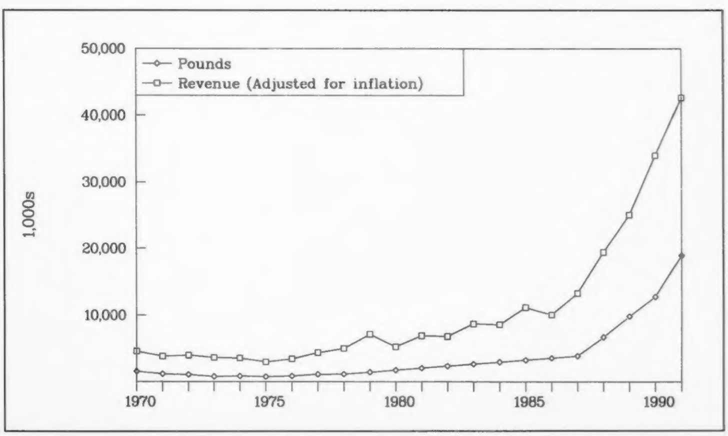

Figure 15.—Hawaii longline landings and revenue, 1970-91. NMFS estimates. Revenue adjusted for inflation to 1990 U.S. $ base.

fishing vessels, would be an attractive avenue for future growth. Unfortunately the recent development of the longline fishery has been less benign, with substantial disputes amongst participants (Pooley, 1990).

The structure of Hawaii's seafood markets has encouraged value-added fisheries development (i.e., the production of a higher quality and higher-priced product through improved handling and marketing and the increased utilization of lower valued species), but with some definite side effects for Hawaii consumers (i.e., higher prices and lower availability). Whereas many mainland U.S. fisheries are "industrial-strength" with poor reputations for quality, low fresh fish prices, and poor incomes for fishermen, in Hawaii the combination of auctions and direct purchases from outside sources has meant a consistently high-quality product. However, fresh fish prices have risen considerably since 1970, even adjusted for the general rate of consumer price inflation (Fig. 16). This has been prompted by the explosion of restaurant demand, where fresh mahimahi can be found on local restaurant menus from Moiliili to Kaanapali, and on the U.S. mainland from Seattle to Des Moines to Boston. For local consumers, the loss of the aku (skipjack tuna) fleet has produced higher retail prices for fresh tuna. Our analysis of the price structure of Hawaii fresh fish prices (Pooley, 1987; Pooley[24, 25]) indicates that the market provides strong quality premiums and is thus a competitive forum for most major fishery producers. However, as the export market develops from the sashimi "niche" to the swordfish "segment," transshipping operations are increasing. This reduces the "local content" of Hawaii's fishery landings, at some detriment to Hawaii's economy and to local consumers.

[24]S. G. Pooley. 1986. Competitive markets and bilateral exchange: the wholesale seafood market in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-86-08, 14 p.

[25]S. G. Pooley. 1991. Revised market analysis: Hawaii yellowfin tuna. NMFS Southwest Fish. Cent., Honolulu Lab. manuscr. 003-91H-MRF.

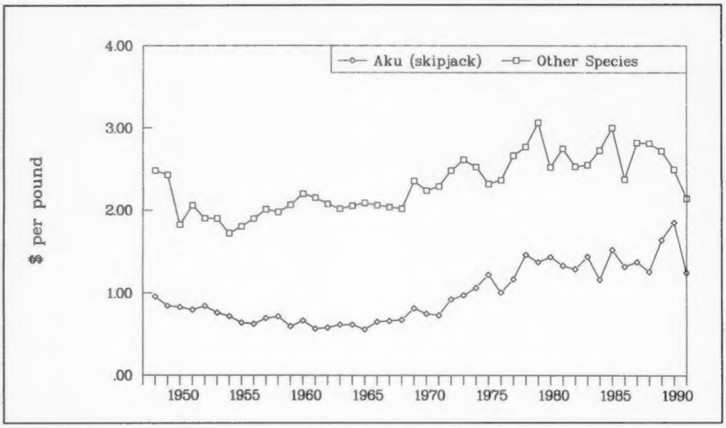

Figure 16.—Hawaii commercial fishery ex-vessel prices, 1948-91. U.S. $ per pound (whole weight). NMFS estimates, aku (skipjack tuna) and all other species. Prices adjusted for inflation to 1990 U.S. $ base.

Recreational Fisheries

The distinction between "recreational" and "commercial" marine fishing in Hawaii's small boat fleets is extremely tenuous. As opposed to most mainland U.S. states, there is relatively easy access to most fishing locations by most residents of Hawaii. Furthermore, and perhaps most important, Hawaii's seafood market is not as centralized and industrialized as mainland fisheries, so that it has always been feasible for small-scale fishermen to sell any or all of their catch for a respectable price. Many people sell a portion of their catch to offset fishing costs, while division of the catch amongst family and friends is also a common practice and indeed in some circles, an important cultural and social obligation. Many people who might be considered "commercial" fishermen in fact hold a full-time or part-time job which provides more income than fishing. Furthermore, charter-fishing boat captains generally retain their catch for sale in the local market, unless explicit arrangements are made to the contrary.[26] Even the catch at major sports fishing tournaments is frequently sold by the charter captains. Not only are there overlapping structural factors in commercial and recreational fishing, but the legalistic differentiation is not particularly helpful. People who catch and sell at least a part of their catch are required to have a State of Hawaii commercial fishing license. However these licenses cost only $25 ($50 to nonresidents), and there is no marine recreational fishing license. Furthermore, there is no active dealer-reporting system, and Federal fisheries management has yet to require permits for the small-boat bottomfish and pelagic fleets.

Because of the lack of information on the small-boat fisheries, a number of survey approaches have been taken to estimate the extent of Hawaii's "recreational" fisheries. The most comprehensive was the NMFS Marine Recreational Fishing Statistical Survey (1979–81) which was a combined telephone and creel intercept survey.[27] The intercept included all modes of marine fishing: shoreline; piers and jetties, private vessel; and charter boat. The telephone and intercepts were fielded by a local company under contract to NMFS headquarters (with minimal actual involvement by NMFS staff in Hawaii), but the statistical expansions were undertaken by a firm on the mainland and delivered only to NMFS headquarters. For reasons not entirely understood, the expansions provided inconsistent estimates of various species and the results were never published. However, if we assume the major source of error was in individual species extrapolation, rather than in total participation and total or aggregate landings, then the following results can be derived.

The 1980 estimates of participation were 2.1 million fishing trips (620,000 by private boats and 88,000 by charter boats, the remainder being shoreside fishing) taken by 235,200 residents and 82,200 visitors (tourists). This amounted to 24% of the de facto resident population. The estimated weight of "recreational" fish caught was 4.4 million pounds, of which 94% was from boat fishing.[28]

In 1984, the Honolulu Laboratory, NMFS, and the Division of Aquatic Resources, State of Hawaii, conducted a survey of vessel owners registered with the State of Hawaii's Department of Transportation[29] (Skillman and Louie[30]; Sumida et al.[31]). Of the respondents who indicated they fished during the year, 70% said they never sold any of their catch, and only 16% sold at least half their catch.[32]

[26]Reporting of catch by charter boats to the Hawaii Division of Aquatic Resources was formalized in 1985. Prior to that, some charter boats reported their catch, and others did not. Charter boats are not explicitly differentiated in the State commercial fish catch reports, although the commercial fishing license identifies these vessels.

[27]Data and methodology for the NMFS Marine Recreational Fishing Statistical Survey in the western Pacific were never published officially. These interpretations are based on project documents obtained by the Honolulu Laboratory several years after the survey was completed.

[28]These estimates were based on samples taken from the 8,033 people who were "intercepted" (sampled) in Hawaii. "Recreational" was not well defined, but is believed to indicate the fish weighed at the sample location were not to be sold. The expansion was based on 4,593 telephone interviews to Hawaii households, of which 15% contained people who went fishing.

[29]Of the approximately 14,500 vessels registered in 1984 with the State Department of Transportation (or documented with the Coast Guard in Hawaii), 12,578 were deemed to have fishing vessel characteristics (cruise liners were excluded, for example). Sixty percent of the questionnaires were completed, with 5,496 vessel owners reporting their vessel was used for fishing. No examination of the nonrespondents was made, so it is not known to what extent returns on this survey were self-selected from fishing vessel owners or not. Presumably 9,200 vessels (60% of the initial population of vessels) could have been used for fishing, but we have tended to use the lower figure as more realistic on the expectation that many people who did not use their boat for fishing would not bother to answer and return a survey oriented

Continued

In 1987 the Hawaii Division of Aquatic Resources surveyed its license holders on a number of issues. Although the response rate was low (30% of the 2,529 license holders responded), the survey appears to confirm the impression that most "commercial" fishing license holders in Hawaii do not make their livelihood from fishing: 80% or more of the respondents on each island indicated they earned less than 51% of their gross income from fishing.

Karl Samples, University of Hawaii, prepared a series of studies on charter boat fishing during the early 1980's for NMFS. Samples found that the charter boat fleet consisted of 119 boats in 1982 (Samples et al.[33]). These vessels are almost entirely 2–6 passenger vessels where half-day and whole-day charters are sold to the group, rather than to individuals (as in U.S. mainland "head" and "party" boats). This fleet generated 73,780 passenger trips with a direct income of $8.1 million[34]. Total fish catch by the charter boat fleet was 2.2 million pounds. It was also estimated that charter boat patrons spent $39 million directly related to charter fishing as a vacation or leisure activity (Samples and Schug[35]).

[29] *Continued*
towards fishing. We also noted through inspection of the respondents that most of the full-time commercial fishing boats also did not respond.

[30]R. A. Skillman and D. K. H. Louie. 1984. Inventory of U.S. vessels in the central and western Pacific: Phase 2—verification and classification. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent. Admin. Rep. H-84-12, 21 p.

[31]R. F. Sumida, B. M. Ito, and J. D Draper. 1985. Inventory and uses of vessels in Hawaii, 1984. NMFS Southwest Fish. Cent., Honolulu Lab., nontechnical rep.

[32]Only 3% of the respondents said they made half their income from fishing, suggesting that the survey returns were biased toward small-scale recreational fishermen.

[33]K. C. Samples, J. N. Kusakabe, and J. T. Sproul. 1984. A description and economic appraisal of charter boat fishing in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-84-6C, 130 p.

[34]Income from charter fees was approximately $5.8 million while income from selling fish was $2.3 million.

[35]K. C. Samples and D. M. Schug. 1985. Charter fishing patrons in Hawaii: a study of their demographics, motivations, expenditures and

The only major study of the economics of recreational fishing in Hawaii was undertaken by Meyer Resources Inc.[20] for NMFS. This study used a variation of the contingent (nonmarket) valuation technique on focus groups composed of recreational fishing clubs in Hawaii. Meyer estimated that there were 6,684 small boats used for "resident" fishing (defined as: "persons who are not making their primary living from commercial fishing," Meyer[20], p. 1) in Hawaii, with direct expenditures of $24 million. Total catch by these vessels was 21 million pounds, of which 47% was sold. The remainder was used for home consumption (23%), given away to friends and family (21%), or otherwise used. Using contingent valuation techniques, Meyer estimated that the nonmarket value of these fishing trips to Hawaii resident fishermen was $239 million.[36]

Finally, in 1990 and early 1991 the State of Hawaii, with the assistance of NMFS, conducted a survey of small boat launch sites and harbors on Oahu (the island on which Honolulu and 80% of the population is situated) to understand better offshore fishing by recreational and subsistence fishermen. The results from this survey may provide a stronger basis for estimating current recreational and part-time commercial fishing activity (Hamm and Lum[37]).

Recent Issues

Naturally, the transition from the old style to the new in Hawaii's offshore fisheries has not occurred without biological, economic, and social impacts. Hawaii's commercial and recreational fisheries are no longer what they were, and the relationship between Hawaii's people and the sea has changed. We have already mentioned the change in availability and price of locally caught fish for Hawaii's resident consumers, but there have been changes in the water and on the docks too.

[35] *Continued*
fishing values. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-85-8C, 95 p.

[36]Nonmarket value means in this case what the participants thought their fishing "experience" was worth in market terms. Frequently this is termed "willingness to pay," as in "How much would you be willing to pay to continue fishing ....?" although that is not the precise approach used by Meyer.

[37]D. C. Hamm and H. K. Lum. 1992. Preliminary results of the Hawaii small-boat fisheries survey. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-92-08, 35 p.

Recognition that nearshore fish resources have diminished (as well as consumer fears concerning ciguatera toxins), combined with the rise in tourism-related ocean recreation, means that there will be more pressure for nearshore marine environment management, with a premium on nonconsumptive uses of marine resources. A number of State of Hawaii initiatives have focused on this recognition, including the Main Hawaiian Islands - Marine Resources Investigation (Pooley[38] and Hawaii Division of Aquatic Resources, 1988), and there has been a broad strategic planning approach to coastal zone management and development (Hawaii Ocean and Marine Resources Council, 1991). Furthermore, rights of native Hawaiians to fishery resources are being explored, primarily through the offices of the Western Pacific Fishery Management Council (Iversen et al., 1989), and these will undoubtedly affect the ultimate resolution to fishery management issues. How Hawaii balances all of these interests may be a major political issue for the 1990's.

There are also some direct competitive pressures accompanying the rapid growth of the longline fishery. The Western Pacific Regional Fishery Management Council (Council) is the center of commercial fisheries management in Hawaii, whereas the state government is concentrating on nearshore fishing issues. The early years of the Council involved laying out a fishery management structure with relatively little emphasis on the distributive issues which were central on the

[38]S. G. Pooley (Editor). 1988. Recommendations for a five-year scientific investigation on the marine resources and environment of the main Hawaiian islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-88-2, 22 p.

U.S. mainland. The NWHI lobster and bottomfish fishery management plans (FMP's) addressed limited fisheries with limited interaction with other fisheries. The pelagic species FMP's orientation was simply toward displacing foreign longline fishing in the Council areas. However, with the growth of the domestic longline fishery in the late 1980's, the Council was suddenly faced with competing domestic issues.

Resolving these pressures has involved a real trade-off between the cost of regulation, in terms of the cost of biological and economic research and in terms of changes in life-styles, and the potential benefits of well-managed natural resources. People who go fishing are frequently very independent, more so than most. All one needs to do is examine the vastness and isolation of their working environment. They are also our most accessible observers of oceanographic conditions and marine biology. It seems that more needs to be done to encourage their community of interests with the rest of Hawaii's ocean and coastal users.

Foreign and U.S. mainland fisheries and markets are also influencing Hawaii's marine fisheries either through biological resource pressure and environmental effects which have led to displaced fleets or changes in market conditions, or through more direct changes in seafood markets. Foreign longline and baitboat fisheries for tuna have fished the central Pacific for decades. Although foreign longline vessels are effectively precluded from fishing within 200 miles of Hawaii (including the NWHI), the tuna and billfish stocks they seek probably are sufficiently migratory to hypothesize an interaction between their distant-water capture and fishing conditions in Hawaii. Furthermore, a number of local entrepreneurs have been exploring the importation of fresh fish directly into Honolulu from foreign longline vessels fishing just outside the U.S. Exclusive Economic Zone. The U.S. purse seine tuna fleet has expanded dramatically into the South Pacific, and the U.S. albacore trollers are now fishing the South Pacific, both using American Samoa as a base. Guam and the Northern Mariana Islands are also used as transshipment centers for purse seine and longline fisheries. The apparent closing down of the Japanese, South Korean, and Taiwanese drift gillnet fleets fishing for squid and albacore tuna, due to their impact on sea birds and marine mammals, may affect both the commercial fisheries of the central Pacific and seafood markets. In addition, there are the potential impacts of ocean mining and other nonfishery related marine developments.

Ironically, perhaps one of the most important economic components of Hawaii's commercial fishing industry is not fishing at all; it is the resupply operations for the hundreds of foreign fishing boats and refrigerated transports which stop in Honolulu harbor for supplies. The direct economic impact of these vessels is $46 million annually (Hudgins and Iversen, 1990). The whole question of harbor infrastructure has been a thorny one even before the original fisheries development plan (Department of Land and Natural Resources, 1979b). Similarly, the relationship between fisheries development and fisheries management and between fisheries and other coastal zone activities (cf. Department of Land and Natural Resources, 1979a) are central to Hawaii's political agenda in the 1990's.

Commercial fishing and the expenditures of the recreational and subsistence fisheries do not comprise a large industry in Hawaii, not even as a percentage of the overall ocean sector, although they are larger than many sectors of diversified agriculture and manufacturing. But fishing has a number of important linkages to Hawaii's current industrial and commercial structure and to Hawaii's cultural heritage. The commercial, recreational, and subsistence fisheries of Hawaii are important barometers of conditions in the ocean environment. Those of us whose job it is to monitor the marine fisheries and to conduct applied research on those fisheries are constantly fascinated by the variation which is displayed. The purpose of this paper has been to provide a better historical framework with which policymakers and the public can assess Hawaii's marine fisheries.

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Biology and Management of Deepwater Snappers of the Hawaiian Archipelago

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Introduction

Commercial exploitation of deepwater snappers in Hawaii began before the turn of the century (Cobb, 1903), and except for a hiatus during World War II, has continued to the present. The fishery operates throughout the Hawaiian archipelago, but the inhabited Main Hawaiian Islands (MHI) experience the highest exploitation by both commercial and recreational fishermen. The uninhabited islands and atolls northwest of Niihau, called the Northwestern Hawaiian Islands (NWHI) (Fig. 1), are fished mainly by commercial fishermen.

The deepwater handline fishery targets a multispecies group of fishes consisting of snappers (Lutjanidae), groupers (Serranidae), and jacks (Carangidae). However, snappers are the most important group in the fishery, both by numbers and revenue.[1] Most of the commercially important species have a relatively high age at maturity, long life span, and slow growth rate. These factors, combined with considerable variation in larval recruitment, make these fishes highly susceptible to overfishing. Recent evidence suggests that some of the species may be overfished, and several others are approaching a level of concern[1, 2] (Ralston and Polovina, 1982; Ralston, 1984).

Historically, minimum size limits have been the only measure used to manage both the MHI and NWHI stocks. Since 1989, the NWHI have been managed on a limited entry system. Minimum size limits remain the only management tool currently in effect in the MHI. Several management measures are being evaluated to maintain adequate spawning stock biomass in the future. These include changing minimum size limits, creating closed refuge areas, and imposing bag limits and closed fishing seasons.

This report presents a summary of available information regarding the biology, fishery, and management of these valuable species.

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ABSTRACT — Commercial and recreational deepwater (100–400 m) bottomfishing in Hawaii targets a multispecies group of lutjanid snappers. Relatively little is known about the life history of these species. Research in Hawaii and elsewhere in the tropical Pacific suggests that most of the species are slow growing, long lived, and have a relatively high age at sexual maturity. Stock assessment is difficult because of the multispecies nature of the fishery. However, recent analysis of commercial fishery data indicates that some of the species may currently be overexploited. Research is underway to determine the efficacy of management measures such as minimum-size limit changes or seasonal and spatial fishery closures to maintain optimal spawning biomass.

[1](WPRFMC) Western Pacific Regional Fishery Management Council. 1991. Annual bottomfish and seamount groundfish report, 85 p.

[2]S. Ralston and K. E. Kawamoto. 1985. A preliminary analysis of the 1984 size structure of Hawaii's commercial opakapaka landings and a consideration of age at entry and yield per recruit. U. S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Admin. Rep. H-85-1, 9 p.

Species and Distribution

The commercially important deepwater snapper complex in Hawaii is composed of seven species of the lutjanid subfamily Etelinae: *Pristipomoides filamentosus* (opakapaka), *P. seiboldii* (kalekale), *P. zonatus* (gindai), *Etelis carbunculus* (ehu), *E. coruscans* (onaga), *Aprion virescens* (uku), and *Aphareus rutilans* (lehi). Some commercial landings of an introduced snapper, *Lutjanus kasmira* (taape), are also made, but this species usually occurs in shallower water than the other species. The commercially important deepwater lutjanids inhabit the deep slopes of island coasts and banks at depths of 100 to 400 m. These banks and deep slopes comprise an area over 6 times that of shallow water reefs in the state. Biological production in these deepwater areas is thought to be quite different from shallow-water coral reef areas (Agegian et al., 1988).

Throughout their spatial and depth range, deepwater snappers in Hawaii are typically distributed in a clumped pattern, and are often associated with underwater headlands and areas of high relief. Four of the deepwater snapper species found in Hawaii were observed in situ from manned submersibles and an unmanned remotely operated vehicle (ROV) and were found to form large aggregations of up to 100 individuals near submerged promontories and areas of high relief (Brock and Chamberlain, 1968; Ralston et al., 1986; Haight, 1989). This clumped distribution pattern is also apparent when fishing from the surface.

A contributing factor in the distribution pattern of these fish may be that

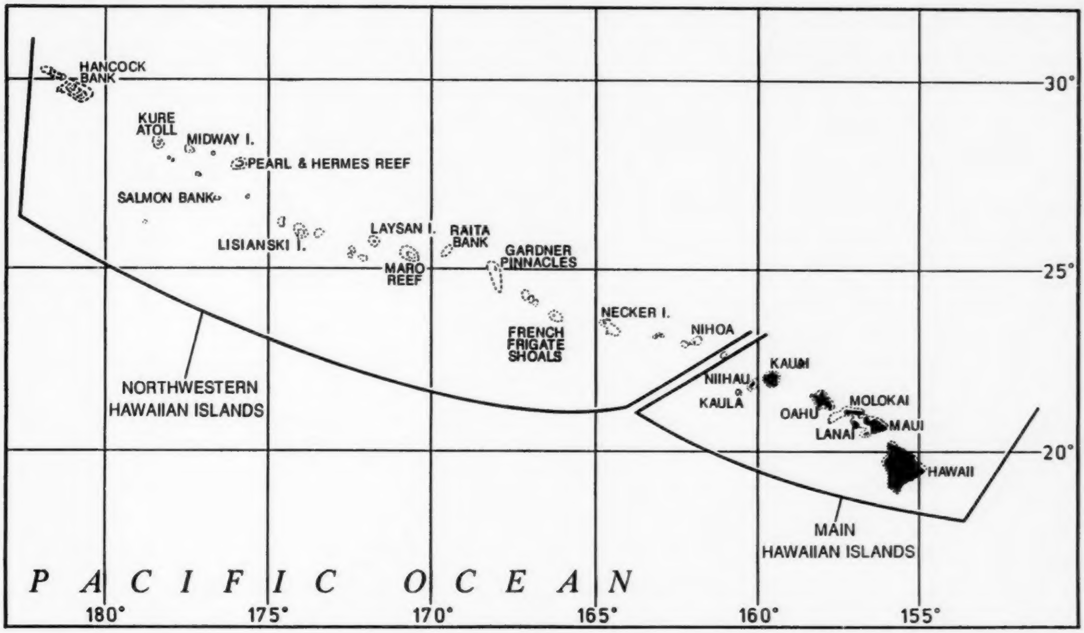

Figure 1. — The Hawaiian Archipelago

currents striking deepwater areas of high relief form localized zones of turbulent vertical water movement, increasing the availability of planktonic prey items (e.g. Brock and Chamberlain, 1968). In an ecological study of the bottomfish resources of Johnston Atoll, Ralston et al. (1986) found *P. filamentosus* in much higher densities on the upcurrent versus the downcurrent side of the atoll, and postulated that this was related to increased availability of allochthonous planktonic prey in the neritic upcurrent areas due to oceanic currents impacting the atoll. Although snappers throughout the world are generally thought of as top level carnivores, several snapper species in the Pacific are known to incorporate significant amounts of zooplankton, often gelatinous urochordates, in their diets (Parrish, 1987). Haight et al. (1993) found zooplankton to be an important prey item in four of the commercially important snappers in Hawaii. The same study found that the six snapper species studied were either primarily zooplanktivorous or primarily piscivorous and showed little overlap in diet composition between trophic guilds.

Reproduction

Relatively little is known about the reproduction and early life history of deepwater snappers in Hawaii. Size at maturity has been estimated for only two species in the MHI and two species in the NWHI. In the MHI, uku reaches sexual maturity at 47 cm fork length (FL), which is 46% of maximum size (L_∞). Onaga reaches sexual maturity at 61 cm FL (62% L_∞) (Everson et al., 1989). In the NWHI, ehu reaches maturity at about 30 cm FL (46% L_∞) and opakapaka reaches maturity at around 43 cm FL (48% L_∞) (Everson, 1984; Kikkawa, 1984; Grimes, 1987).

There is a record of one anecdotal observation on the spawning behavior of opakapaka in Hawaii. A NWHI commercial fisherman using a chromoscope depth sounder observed an opakapaka aggregation at about 150 m become very dense during the mid-morning hours. Catch rates decreased at this time, and egg masses were observed adhering to the fishing gear. By mid-afternoon the school became less compacted and catch rates increased. Opakapaka caught during this time were in spawning condition, some females released eggs and males released milt. Free-floating eggs were noted covering a large surface area around the vessel. The observations were made in mid-April.[3]

Gonadal studies on four of the species in Hawaii indicate that spawning may occur serially over a protracted period but is at a maximum during the summer months, and peaks from July to September (Everson et al., 1989; Uchida and Uchiyama, 1986). Estimated annual fecundity is 0.5 to 1.5 million eggs. The eggs are relatively small (0.7 to 0.8 mm) and are released into the water column.

[3](WPRFMC) Western Pacific Regional Fishery Management Council. 1988. 1986 annual report of the fishery management plan for the bottomfish and seamount groundfish fisheries of the western Pacific region, 150 p.

Larval and Juvenile Stages

Newly hatched larvae of lutjanids in general are typical of those from fish with small pelagic eggs; the larvae have a large yolk sac, unpigmented eyes, and no mouth. The yolk sac typically lasts 3–4 days, after which the mouth is fully formed and the eyes become pigmented (Leis, 1987). The larval stages of snappers in Hawaii are poorly studied, perhaps because of their rarity in plankton samples. In a 16-month survey of the larval fishes near Oahu, snappers of the subfamily Etelinae were taken exclusively in the late summer and fall, and occurred in very low numbers, making up less than 0.5% of the 5,200 fish larvae identified (Clarke, 1991). Snapper larvae are thought to be planktonic and subject to advection by ocean current systems until benthic habitat suitable for metamorphosis is encountered (Munro, 1987). The duration of the pelagic phase is thought to be at least 25 days (Leis, 1987).

Little information currently exists on larval development, settlement, or early juvenile life history of deepwater snappers in Hawaii. Despite considerable research effort directed toward snapper productive processes in Hawaii, little is known about the ecology of juveniles from time of settlement to their appearance in the adult fishery. Age at entry to the fishery for the principal species is thought to be 2 to 3 years after settlement.[4] In a three-year study of fish settlement on artificial reefs adjacent to adult snapper habitat in Hawaii, no recruitment of juvenile snappers to the reefs was observed, although adults aggregated at times around the reef structures (Moffitt et al., 1989).

Occasional reports of recreational fishermen taking juvenile opakapaka while fishing in depths less than 100 m prompted exploratory research fishing to be conducted in these nearshore areas. Results from a 13-month intensive fishing program off Kaneohe Bay, Oahu, Hawaii indicated juvenile opakapaka first appear in the relatively shallow (60–100 m) nearshore areas at about 10 months of age (7–10 cm FL) during the fall and early winter months. The young opakapaka remain in this habitat for the next 7 months until they reach 18–24 cm FL.[5] In situ scuba observations of the juvenile habitat found it to be a relatively flat, soft sediment substrate devoid of relief (Parrish, 1989). Recent trawl surveys suggest juvenile opakapaka are fairly widespread throughout the MHI in similar habitat and depths.[6]

Age, Growth, and Mortality

Tropical snappers in general are slow growing, long lived, and have low rates of natural mortality. Maximum ages exceed 10 years, and von Bertalanffy growth coefficients (K) are usually in the range of 0.10 to 0.25 per year (Manooch, 1987). Most aging studies of tropical snappers have depended on the enumeration of regularly formed marks on calcareous structures. The extended reproductive cycles and weakly expressed seasonality of growth in these fishes, however, confounds the accuracy of such studies. In Hawaii, Ralston and Miyamoto (1983) used daily growth increments deposited on the otoliths of immature *P. filamentosus* to determine its growth rate. Using in vivo tetracycline injection as a validation technique, they concluded that daily otolith increments were deposited in fish up to 3 years old (sexually mature), however, aging of fish greater than age 3 was difficult owing to episodic otolith deposition in sexually mature fish. Based on the growth of immature fish, the estimated growth coefficient of opakapaka was 0.145 per year, and asymptotic upper boundary on growth (L_∞) was 78 cm FL, which occurred at over 18 years of age.

Ralston (1987), in a comprehensive review of published reports on snapper growth and natural mortality, determined that for the 10 species studied, mortality and growth rates were highly correlated, with a mean M/K ratio of 2.0. Thus, if a value of K is available for a given species, its natural mortality rate can be estimated. Using an age-length probability matrix for opakapaka applied to length frequency samples, Ralston (1981) estimated the natural mortality rate for opakapaka in Hawaii to be 0.25, which when compared to the estimated K value for this species (0.145) is close to the value predicted by the M/K relationship derived for snappers in general.

Fishery Synopsis

Deepwater snapper in Hawaii have been commercially exploited since the early part of the century. In 1925, the Territorial Legislature, concerned with an increasing level of fishing pressure, imposed a one-pound minimum size limit for most of the deepwater snappers. By the 1930's, a fleet of vessels fished for bottomfish throughout the archipelago, with as many as five large (20 m) vessels venturing into the NWHI. After the hiatus imposed on the fishery by WWII, as many as nine vessels fished the NWHI. Landings peaked in the early 1950's at about 500 t, and declined steadily through the mid-1970's (Fig. 2). In the mid-1950's, poor fish prices and vessel losses reduced the number of fishermen in the NWHI; by the 1960's only one vessel remained in operation in the NWHI (Hau, 1984). There was renewed interest in the resources of the NWHI in the mid-1970's when state and federal agencies collaborated in a study focusing on the resources of this region. Bottomfish resources within this area were investigated during conducting an economic study of the fishery. The potential of the NWHI bottomfish resource prompted many new fishers to enter the fishery.

During the late 1970's, the fleet exploited banks closest to the MHI ports. As yields decreased, the fleet moved farther into the NWHI. A few vessels with extended fuel and hold capacity

[4] S. Ralston and K. E. Kawamoto. 1987. An assessment and description of the status of bottom fish stocks in Hawaii. U. S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent. Admin. Rep. H-87-7, 55 p.

[5] R. B. Moffit and F. A. Parrish. In review. Temporal and spatial utilization of habitat by juvenile Hawaiian pink snapper, *Pristipomoides filamentosus*.

[6] D. A. Ellis, E. E. Demartini, and R. B. Moffitt. 1992. Bottom trawl catches of juvenile opakapaka, *Pristipomoides filamentosus* (F. Lutjanidae), and associated fishes, Townsend Cromwell cruise TC-90-10, 1990. U. S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-92-03, 33 p.

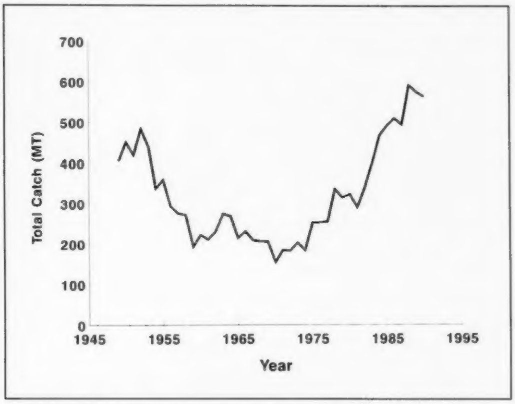

Figure 2. — Annual commercial bottomfish landings for the entire Hawaiian Archipelago, 1948–1990. (State of Hawaii, Division of Aquatic Resources data)

were fishing around Midway and Kure by 1988. The fishery expanded rapidly in the 1980's and landings peaked in 1987 (Fig. 2). Increased fishing pressure and fluctuating exploitation rates in the NWHI prompted the Western Pacific Regional Fishery Management Council (WPRFMC) to impose a limited access system for a large part of this area in 1989. Currently, effort in the portion of the NWHI west of Necker Island (Fig. 1) is limited to 6 vessels.

Fishing Gear

The Hawaiian snapper fishery utilizes various modifications of traditional Hawaiian handline gear. The gear consists of a main line with a 2–4 kg weight attached at the terminus. Several 40–60 cm sidelines with circle hooks are attached above the weight at 1 m intervals. The basic design of the handline gear used in the fishery has remained essentially unchanged from gear used by early, indigenous Hawaiians.

Commercial snapper fishermen in Hawaii mainly utilize vessels 10–20 m in length. The vessels are usually equipped with color video depth and fish echo sounders, satellite navigation receivers, Single Side Band (SSB) and VHF radios, EPIRB's, and hydraulic line-pulling equipment.

Vessels venturing into the NWHI tend to be in the upper end of the size range, as distance from ports and lack of rough-weather shelter keep many of the smaller vessels closer to their home ports. The MHI vessels, although smaller than those used in the NWHI, are similarly equipped.

There are also many part-time recreational/commercial fishermen in the MHI. The boats involved in this fishery are smaller than the full-time commercial vessels and usually range from 5 to 15 m in length. Most of the part-time fishermen have color video depth/fish sounders, CB radios, and electric line-pulling equipment. Many also have satellite navigation equipment.

Since the late 1960's, the availability of improved navigational and fishing gear has greatly increased the fishing power of both commercial and recreational fishermen in Hawaii. It is now possible to return to a particular fishing spot with great accuracy in various weather conditions using electronic navigation equipment and to target single species using color video sounding equipment. In the past, triangulation from visible onshore landmarks was the most common method of relocating productive fishing grounds. This method can be very accurate, but depends on weather and other conditions beyond the control of the fisherman.

Until recently, many fishermen targeted individual species of snappers, but this strategy is not commonly practiced today. Most fishermen now diversify fishing effort because of decreased catch rates for some of the species. Targeting different species of snapper seasonally, or fishing for pelagic species when bottomfish are scarce, is now commonly practiced.

Seasons and Markets

The various snapper species are mainly caught during the months of November–February, with peak catches in December. Uku is an exception in that it is heavily exploited during the summer months when it aggregates in shallow water to spawn. Some uku are landed incidentally in December owing to increased fishing pressure on opakapaka which occurs at the same depths as uku.

A large portion of the MHI snapper landings is taken by recreational fishermen; therefore, the NWHI commercial fishery plays an important role in providing a consistent supply of fresh bottomfish to local markets. Generally the demand for fresh fish outstrips the supply. Snapper from various Pacific island nations are imported at times to supplement the supply of local fish. In the past these imports generally were of lower relative quality; however, in recent years the quality of these imports has improved dramatically. The price of these imported fish has also increased but is still lower than that of comparable local fish. The seasonal abundance of these imports can affect the price of the local bottomfish. However, most imports occur during the local low season for bottomfishing, which contributes to a year-round consistent supply of fish.

Most commercial fish in Hawaii are sold at wholesale fish auction houses. The demand for freshness and quality is high. Ex-vessel price can vary considerably depending on the quality of individual lots of fish. Snappers are generally separated into two categories at the auction: 1) large fish for the restaurant fillet market and 2) smaller whole fish for local consumers. Demand from local tourist-oriented restaurants is the major factor in bottomfish market economics. The local consumer market for smaller fish fluctuates to some extent, with peak demand occurring during traditional winter holidays.

Fishery Data Collection

In Hawaii, fishermen who sell all or part of their catch must be commercially licensed and submit a monthly catch report. These data have been available from the State of Hawaii Division of Aquatic resources (HDAR) since 1948. In the MHI, incomplete reporting, and the "under-the-table" selling of fish by recreational fishermen confound the accuracy of the catch reporting system. In 1984 the WPRFMC initiated a monitoring program at the Honolulu fish auction to provide additional information on bottomfish landings in Hawaii. In 1986 the NMFS assumed responsibility for the program. In 1990, the HDAR began to share monitoring duties with the NMFS on a half-time basis. During the years 1984 through 1987, monitoring was conducted six days per week. This was reduced to five days per week in 1988, and three days per week in 1992. Information collected includes name of vessel or fisherman, date of sale, general area fished, species of fish, number of fish and corresponding weight, price per pound, and buyer. Information is recorded on a data sheet, coded and keypunched for analysis. Until recently, the majority of snapper sold in Hawaii passed through the monitored site. However, beginning in 1991, the majority of NWHI landings were not sold at the monitored site, which increased the difficulty in monitoring total archipelago landings.

An additional problem in obtaining total archipelago catch information is the large number of fish landed by recreational fishermen and not reported. The MHI recreational catch of snapper is impossible to accurately estimate. The large number of small trailerable boats currently registered in Hawaii gives an indication of the magnitude of the problem. Many of these "recreational" fishermen often sell their catch disregarding commercial fishing license requirements. The ease of selling privately to wholesalers, retail fishmarkets, restaurants, supermarkets, peddling, etc., without the proper licenses or reporting, leads to serious underestimation of total state catches.

Stock Status and Population Dynamics

Several different stock assessment approaches have been applied to the Hawaiian deepwater snapper fishery. These will be reviewed in approximate order of methodological complexity, which is similar to their chronological order in time because of developments in stock assessment methods and/or availability of additional data.

Simple catch per unit of fishing effort (CPUE) of commercial fishermen or research vessel surveys is commonly used as an index of stock abundance. CPUE alone can only provide estimates of relative changes in abundance; but, when coupled with certain assumptions and cast in the proper mathematical framework, it is possible to obtain measures of absolute abundance by estimating a catchability parameter. Catchability can be estimated in several different ways, and one of the more common approaches is to use the catch data in a surplus production model which will also estimate other fishery statistics such as maximum sustainable yield. Ralston and Polovina (1982) used a Schaefer surplus production model in one of the earliest attempts to assess MHI deepwater snapper stocks. The parameters for this model were estimated from a linear regression of yearly CPUE on yearly effort over the time period 1959–1978 (HDAR data). Rather than fit individual models to each species, Ralston and Polovina found that an intermediate level of species aggregation (from the species pool of 8 deepwater snappers) resulted in significantly improved fits to the model. This was apparently due to both depth segregation by species and the multispecies nature of the fishery where, since fishing effort (in fisherman-days) is not necessarily directed at a single species, single species CPUE, calculated by using the aggregate fishing effort, does not reflect that species abundance. Ralston and Polovina sought to aggregate species in the analysis to essentially mimic the aggregate nature of the fishing effort. This optimal level of species aggregation was objectively determined through cluster analysis of species weight composition in HDAR daily commercial catch reports. The potentially complex effects of interaggregation interaction (i.e. predation, competition, and mutualism) were statistically examined and dismissed. Of the four MHI regions examined, statistically significant models were consistently achieved only for the Maui-Lanai-Kahoolawe-Molokai (MLKM) region (Fig. 1), an area which accounts for over 50% of the statewide bottomfish landings. This provided an estimate of MSY per habitat area which was then used in conjunction with other habitat area estimates to extrapolate other regional and total MSY's in the MHI and NWHI. Ralston and Polovina concluded that the MHI aggregate bottomfishery was operating at or near MSY in 1978, and in more recent years both MHI and NWHI landings have consistently exceeded estimates of MSY[4,7] (Polovina, 1987), a situation difficult to interpret for purposes of stock assessment. The next level of stock assessment approaches for Hawaiian deepwater snappers attempted to utilize information on age and growth and patterns of size/age at entry to the fishery on a species-specific level.

Assessment of Hawaiian deepwater snappers in the 1980's relied heavily on the Beverton and Holt (1957) approach, also referred to as dynamic pool modelling. The normal methodology is simply to use the equations presented by Beverton and Holt (1957), inserting where necessary the von Bertalanffy growth coefficient (K) or asymptotic length ($L\infty$) parameters, values of total, natural, or fishing instantaneous mortality (Z, M, or F), and ages at maturity or entry to the fishery (t_m or t_e). Since this complete set of information is not available for many species of Hawaiian deepwater snappers, alternative methods must often be used to solve the yield equation.

The first alternative method is to estimate independently as many parameters as are within the limits of the

[7]S. Ralston and K. E. Kawamoto. 1988. A biological assessment of Hawaiian bottom fish stocks, 1984–87. U. S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent. Admin. Rep. H-88-8, Honolulu, Hawaii, 60 p.

database, and then use empirical relationships to estimate the remaining parameters. Ralston and Kawamoto[7] used this approach for five species of Hawaiian bottomfish (including four species of deepwater snappers: ehu, onaga, opakapaka, and uku), starting with estimates of $L\infty$ and the ratio Z/K from application of the Wetherall et al. (1987) method on catch length frequencies. These length frequencies were converted from Honolulu auction weight data by using the length-weight conversion parameters from Loubens (1980), Uchiyama et al. (1984), Brouard and Grandperrin (1984), and Ralston (1988). The empirical relationship presented in Manooch (1987) was used to estimate K from $L\infty$, and the empirical relationship presented in Ralston (1987) was used to estimate M from K. The mortality parameters Z and F were deduced algebraically, where $Z=(Z/K)K$ and $F=Z-M$. Ages at entry were estimated from the ascending limbs of the weight frequency distributions, by using the length-weight conversion parameters and $L\infty$ and K (assuming $T_0=0$). The estimates of $L\infty$ and K were further used to construct a length converted catch curve from the length frequency distributions (also assuming $T_0=0$), resulting in another estimate of Z. Ralston (1984) also estimated M from $L\infty$, K, and water temperature using the empirical formula given in Pauly (1980). Generally, multiple estimates of a parameter were averaged when they were in close agreement. Ralston and Kawamoto[7] concluded that NWHI stocks were healthy, but most MHI stocks were being growth overfished by excessive harvesting of juvenile fish. They recommended some form of management regulation to counteract this.

The second alternative method is to modify the yield equation to a form which uses the ratios Z/K, M/K, or F/K rather than Z, M, F, or K since the former are readily calculable by using the Wetherall et al. method on weight-converted length frequency samples from a fished population (where $Z/K=M/K+F/K$) and an unfished population (where $Z/K=M/K$). F/K can then be solved for by subtraction, $F/K=Z/K-F/K$. This was suggested by Polovina (1987) and implemented by Somerton and Kobayashi[8] to calculate the spawning potential ratio (*SPR*=ratio of current spawning stock biomass per recruit to the virgin spawning stock biomass per recruit) for two species of MHI deepwater snappers (ehu and opakapaka). This analysis assumed that length frequencies of NWHI catch approximated a virgin unfished condition. Somerton and Kobayashi[8] concluded that *SPR* values were in the 20–30% range which borders on the 20% value generally accepted as an indicator of recruitment overfishing (Beddington and Cooke[9]).

Both of these ad hoc applications of Beverton-Holt probably suffer from biases because of the variety of approximations and assumptions. One bias potentially affecting both approaches is due to use of the Wetherall et al. method to estimate initial parameters of the analyses. Somerton and Kobayashi (1991) used computer simulation to show that estimates of Z/K and $L\infty$ from the Wetherall et al. method can be either positively or negatively biased for many years while the population is adjusting to a change in fishing intensity or from a recruitment perturbation (however, bias due to recruitment seasonality per se can be negligible [Ralston, 1990]). Even under equilibrium conditions there can be substantial bias due to error in estimating the size at complete fishery selection and growth variability (Somerton and Kobayashi, 1991; Issac, 1990). In their assessment of the 1988 bottomfish stock, Somerton et al.[10] abandoned the Beverton-Holt approach because of uncertainties regarding this type of bias; however, as mentioned previously, Somerton and Kobayashi[8] applied the Z/K, M/K, F/K version of Beverton-Holt to estimate *SPR* for ehu, which does appear to be in equilibrium, and for opakapaka, for which there are additional data on size at complete fishery selection.

Ralston and his coworkers[2,4,7] (Ralston, 1981, 1984; Ralston and Miyamoto, 1983) have assembled an extensive database on the biology and fishery for opakapaka, which is by far the single best known species of Hawaiian deepwater snapper. For this reason, assessment approaches for opakapaka require fewer assumptions and approximations, and often there are multiple estimates available for a desired parameter. Ralston (1984) and Ralston and Kawamoto[2] applied yield-per-recruit analyses to opakapaka which made use of many independently estimated parameters. Von Bertalanffy parameters were obtained from a study of otolith microstructure (Ralston and Miyamoto, 1983), and Z and M were estimated from length converted catch curves from fished and unfished areas, and age at entry was estimated from the ascending limbs of catch weight frequency distributions, by using length-weight conversion and von Bertalanffy parameters.

Somerton and Kobayashi[8] developed a computationally simple dynamic estimator of *SPR* that makes use of a time series of CPUE and catch size frequencies. Assuming that CPUE is an index of population size, changes in CPUE over time, coupled with the changes in the catch size composition, can be used to make estimates of *SPR*. Resorting to a similar strategy as that of Ralston and Polovina (1982), Somerton and Kobayashi[8] aggregated species in the CPUE index and were able to calculate species-specific dynamic *SPR* for five MHI bottomfish species (including four species of deepwater snappers: ehu, onaga, opakapaka, and uku) by utilizing species-specific catch size frequency distributions and sizes at maturity. These dynamic *SPR* values were similar to the equilibrium SPR values, falling in the range of 20–40%. The earliest

[8]D. A. Somerton and D. R. Kobayashi. 1990. A measure of overfishing and its application on Hawaiian bottomfishes. U. S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-90–10, 18 p.

[9]J. R. Beddington and J. G. Cooke. 1983. The potential yield of fish stocks. FAO Fish. Tech. Pap. 242, 47 p.

[10]D. A. Somerton, B. S. Kikkawa, and A. R. Everson. 1989. Biological assessment of the Hawaii bottom fish stocks and the southeast Hancock Seamount armorhead stock, 1988. U. S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent. Admin. Rep. H-89–6, 34 p.

(1948) CPUE data were considered virgin, but it is known that considerable bottomfishing may have been taking place at least as early as the 1930's (Polovina, 1987); and no attempt was made to correct for technological improvement in fishing efficiency. Clearly, there is a need for some type of dynamic stock estimator which does not rely on CPUE.

The logical alternatives are dynamic production modelling or age-structured models. The former approach is handicapped by incomplete landings and effort data, and the lack of a reliable CPUE. The latter approach may be more suitable, particularly since more age and growth data are available from ongoing otolith studies. Preliminary application of stock-synthesis, an age-structured model developed by Methot (1989, 1990), to NWHI opakapaka has been favorable[11], and a synthesis-like equilibrium approach called IMMAGE (Somerton and Kobayashi, 1992) has been successfully used to estimate recruitment, fishing mortality, and the gear selection curve for MHI and NWHI opakapaka[11]. Currently, the 1991 stocks are assessed with the CPUE-based dynamic *SPR* method.

Management and Regulation

Current fishing regulations for Hawaiian deepwater snappers include commercial minimum size limits of 1 pound for opakapaka, onaga and uku, and limited entry in the NWHI. There are no bag limits, closed seasons, or recreational minimum size limits for any deepwater snapper.

Somerton and Kobayashi[12, 13] explored the possible consequences of increasing the minimum size limit for opakapaka from 1 to 3 pounds or initiating a 1–3 month seasonal closure of the fishery. Their results from computer simulation indicated that both management strategies could substantially benefit the fish population in terms of increasing the spawning stock biomass. The potential increases ranged from 15–300% after a time period of 5–10 years, depending on the initial condition of the stock. Maximal benefits are attained if sublegal fishing mortality is minimal (i.e. small fish are avoided or released alive) in the case of a size limit increase, and if a seasonal closure effectively reduces the total annual fishing mortality (i.e. there is no compensatory increase in fishing effort during the open season). It is unlikely that the long-term equilibrium yield would increase; however, the population would be less vulnerable to recruitment overfishing and the associated catastrophic stock decline. The State of Hawaii is currently evaluating these and other management options (e.g. bag limits, areal closures) in response to concerns of deepwater snapper overfishing, primarily in the MHI.

Research Needs Pertaining to Management

Details of the reproductive biology are minimally adequate for most of the primary Hawaiian deepwater snapper species. More age and growth studies are needed, particularly for the younger and smaller fish, with enough data to better define the magnitude of growth variability. Discrepancies in growth estimation due to methodological differences in aging (e.g. Morales-Nin and Ralston, 1990; Radtke, 1987; Smith and Kostlan, 1991) need to be addressed and resolved, as this information forms the foundation for cohort/virtual population analysis, or stock synthesis assessment models. Movement patterns of adults and the extent of egg and larval dispersal need further study to clarify the identity of individual stocks, which would help determine the temporal and spatial scale for effective management.

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The Lobster and Shrimp Fisheries in Hawaii

JEFFREY J. POLOVINA

The Lobster Fishery

Introduction

The commercial lobster fishery in Hawaii is a trap fishery which harvests several lobster species in the Northwestern Hawaiian Islands (NWHI)—an isolated range of islands, islets, banks, and reefs extending 1,500 n.mi. northwest, from Nihoa Island to Kure Atoll (Fig. 1). The fishery targets two species: the endemic spiny lobster *Panulirus marginatus* (Quoy and Gaimard, 1825) and the common slipper lobster *Scyllarides squammosus* (Milne-Edwards, 1837) (Fig. 2,3). Two other species—the ridgeback slipper lobster *S. haanii* (de Haan, 1841) (Morin and MacDonald, 1984) and the Chinese slipper lobster *Parribacus antarcticus* (Lund, 1793)—are caught incidentally in low abundance.

Lobster concentrations in the NWHI were documented by research cruises in 1976, and commercial trapping began in 1977 (Uchida and Tagami, 1984). Since 1983, the lobster fleet has ranged from 9 to 16 vessels (15 to 35 m long), each averaging 3 trips per year. A typical vessels sets about 800 traps per day and remains at sea almost 2 months per trip. The NWHI lobster fishery is Hawaii's most valuable demersal fishery; in recent years, annual landings have averaged about 600 metric tons (t) (1 million lobsters), valued at about $6 million U.S. ex-vessel (Fig. 4). Since 1988, about 80% of the landings have been spiny lobster (Polovina[1]).

A commercial shellfish trap made by Fathoms Plus[2] is used by all the fishermen. This is a dome-shaped, single-chambered trap made of molded black polyethylene which measures 980 × 770 × 295 mm, with a mesh size of 45 × 45 mm (inside dimensions). Each trap has two entrance cones located on opposite sides. Each trap also has two escape vent panels each consisting of four 67 mm diameter circular vents located on opposite sides to facilitate the escapement of sublegal lobsters (lobsters under minimum legal harvest size). The traps are typically baited with chopped mackerel (*Scomber* sp.) and fished in strings of several hundred traps per string most frequently set in depths from 20 to 70 m.

Synopsis of the Fishery

The historical landings from the lobster fishery exhibit a classical trend of a developing fishery with a period of low catches at the beginning of the fishery (1977–83) followed by a rapid increase in landings as more vessels entered the fishery and markets were developed (1984–86) and most recently a decline in landings as the population is reduced by overfishing (1987–91) (Fig. 4). In the early years of the fishery (1977–84) and since 1988, landings have been about 80% spiny and 20% slipper lobsters. However, for a three-year period from 1985 to 1987 the fishery targeted and largely depleted a previously lightly exploited population of slipper lobsters.

Stock assessment has used the annual catch of spiny and slipper lobsters and trapping effort data from the commercial logbooks since 1983 (Table 1).

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ABSTRACT — A description of the lobster and deepwater shrimp fisheries in Hawaii, addressing harvest levels, biology, and research, is presented. Both fisheries are trap fisheries. The lobster fishery is a limited entry fishery with 1991 landings of 200 metric tons. The shrimp fishery is unregulated, with very sporadic effort, and annual landings below 200 metric tons.

[1]J. J. Polvina. 1991. Status of lobster stocks in the Northwestern Hawaiian Islands, 1990. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-91-04, 16 p.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Annual landings of spiny and slipper lobsters (in 1,000's), trapping effort (in 1,000's trap-hauls), and the percentage of spiny lobster in the landings, 1983–90.[1]

Year	Spiny lobster	Slipper lobster	Total lobsters	Trapping effort	CPUE	Spiny lobster %
1983[2]	158	18	176	64	2.75	90
1984	677	207	884	371	2.38	78
1985	1022	900	1922	1041	1.83	53
1986	843	851	1694	1293	1.31	50
1987	393	352	745	806	0.92	53
1988	888	174	1062	840	1.26	84
1989	944	222	1166	1069	1.09	81
1990	591	187	778	1182	0.66	76
1991[3]	131	35	166	292	0.56	79

[1] Data were provided to the Honolulu Laboratory, National Marine Fisheries Service, as required by the Crustacean Fishery Management Plan of the Western Pacific Regional Fishery Management Council.
[2] April-December 1983.
[3] January-May, November-December 1991.

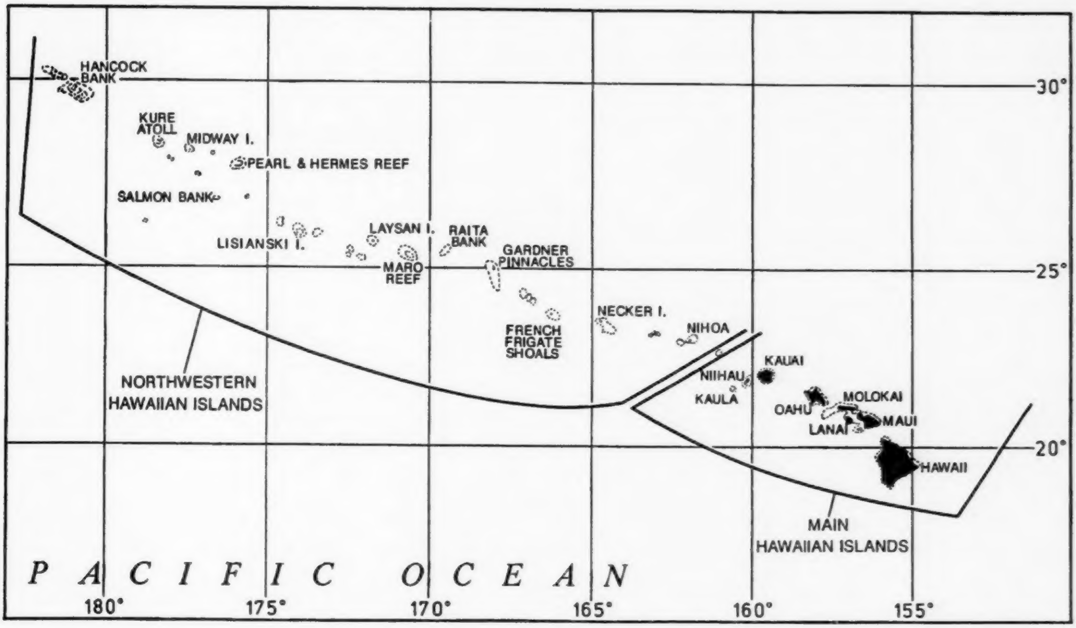

Figure 1.—The Hawaiian Archipelago, including the Northwestern Hawaiian Islands.

Both spiny and slipper lobsters may be caught in the same trap but fishermen can alter the proportion of each species by selecting the trapping area and depth. Logbooks record only the number of traps hauled and do not specify when effort targets spiny or slipper lobster. Since 1983 when logbook reporting was in effect, the combined catch per unit effort (CPUE) for legal slipper and spiny lobsters has declined from 2.75 to 0.56 lobster per trap-haul (Fig. 4).

Stock assessment of the lobster resource is hindered by the relatively short catch and effort time series and our inability to age lobsters. A dynamic production model, fit to the combined spiny and slipper lobster catch and effort data for the entire NWHI, estimates an equilibrium production curve with a maximum sustainable yield of 900,000 lobsters/year from a fishing effort of 740,000 trap-hauls, resulting in a CPUE of 1.22 lobsters/trap-haul (Polovina[1]). A CPUE time-series model estimates the annual instantaneous natural mortality (*M*) at 0.7/year and catchability (*q*) at 1.0×10^{-6} (Polovina[1]). Thus the 1990 fishing effort of 1.2 million trap-hauls corresponds to a fishing mortality (*F*) of 1.2/year or 1.7 times *M*. Based on the minimum harvest sizes and this level of fishing mortality, the spawning stock biomass per recruit is estimated at 40% of the level in the absence of fishing.

Both the level of fishing mortality relative to natural mortality and the relative spawning biomass suggest that fishing effort alone was not sufficient to cause the decline in CPUE observed in 1990 and 1991. Current research suggests this decline is the result of poor recruitment (due to oceanographic conditions) at some banks which resulted in a concentration of fishing effort at the remaining banks where recruitment was strong.

Research

After the initial research cruises documented lobster concentrations in the NWHI in 1976, research focused on the biology of the spiny lobster *Panulirus marginatus*. Tagging studies at Kure Atoll and French Frigate Shoals estimated a von Bertalanffy growth curve for growth (in carapace length) to have a parameter *K* of 0.31/year with an asymptotic carapace length of 13.2 cm, a mean natural mortality estimate of 0.37/year, and estimates for the ages at the onset of sexual maturity of 2.7 and 1.7 years for males and females, respectively (MacDonald, 1984). Trapping surveys mapped the spatial distribution of *P. marginatus* in the NWHI and indicated that the highest catch rates ranged from depths of 55–73 m in the southeastern portion of the NWHI to 19–54 m in the northwestern portion of the Hawaiian Archipelago (Uchida and Tagami, 1984). The settlement of post-larval lobster, puerulus, were monitored at Kure Atoll, French Frigate Shoals, and Oahu with surface collectors (MacDonald, 1984). Puerulus settlement appeared seasonal at the ends of the Hawaiian Archipelago; the greatest settlement occurred in the summer at Kure Atoll and in the winter at Oahu while at French Frigate Shoals, more centrally located, settlement appeared more uniformly throughout the year (MacDonald, 1986).

Research conducted during 1984–87 developed escape vents to reduce the catch and hence mortality of sub-

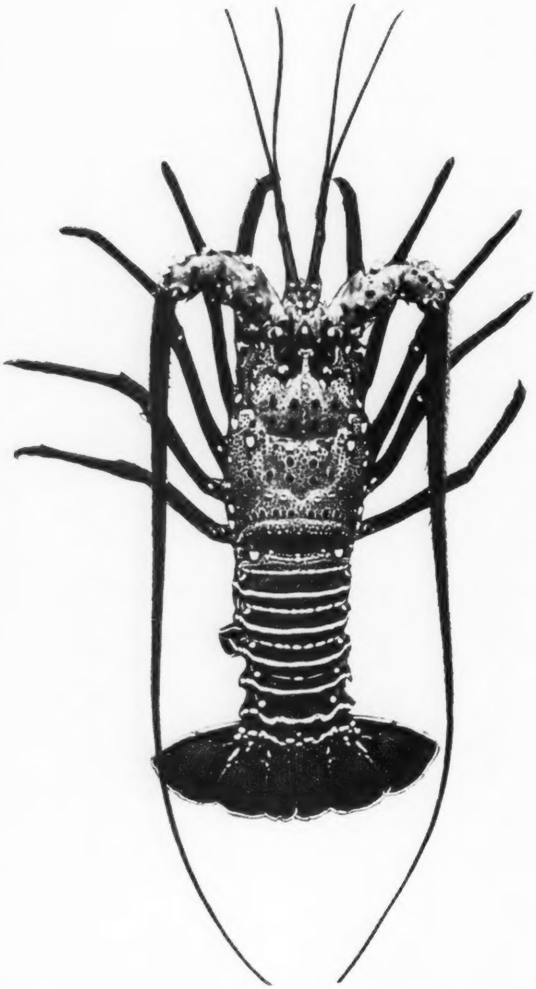

Figure 2.—The spiny lobster, *Panulirus marginatus*.

legal spiny lobster (<50 mm tail width) and sublegal slipper lobster (<56 mm tail width) without reducing legal catches. A circular vent design takes advantage of the different morphology of the spiny and slipper lobsters to allow escapement at different tail sizes for each species. Specifically, research found that traps equipped with two vent panels consisting of four 67 mm diameter circles placed at the bottom of the trap caught 83% and 93% fewer sublegal spiny and slipper lobsters than did nonvented control traps, without significantly reducing legal catches of either species (Everson et al., In press).

An estimated 2,000 plastic traps are lost annually in the NWHI. Concern has been raised that lobsters entering those lost traps may be unable to exit and therefore die. Recent field and tank studies have investigated whether lobsters can escape unbaited lobster traps. The results indicate that lobsters using the traps for shelter are able to exit, and no mortality due to the retention of slipper or spiny lobster in traps was observed (Parrish and Kazama, 1992).

Ongoing research is directed toward understanding the factors responsible for observed spatial and temporal variation in adult lobster abundance within the Hawaiian Archipelago. Results from larval tows and studies on local oceanography suggest that long-term differences in lobster densities between banks in the NWHI are not due to local larval densities but to differences in the amount of relief provided by the benthic habitat on the banks.

Temporal variation in spiny lobster stocks at the two most productive banks in the fishery, Maro Reef and Necker Island, has been studied with both commercial and research data. Research and commercial trapping data both show a wide variation in recruitment to the fishery for spiny lobster at Maro Reef relative to Necker Island, 360 n.mi. to the southeast. A high correlation is observed between recruitment to the fishery at Maro Reef and the relative sea level between French Frigate Shoals and Midway Island four years earlier. Geosat altimeter data indicate that the variation in relative sea level between French Frigate Shoals and Midway is linked to the El Niño Southern Oscillation (ENSO). The mechanisms responsible for the apparent link between sea level and lobster recruitment are not known and are the subject of current research. However, the sea level index may prove to be a useful forecast of recruitment to the fishery at Maro Reef four years later (Polovina and Mitchum, 1992).

One economic study (Clarke and Pooley, 1988) has examined the return on investment as a function of vessel size. The most profitable vessels in the fleet are the midsize vessels. These vessels are 20–30 m long, have 5–9 crew members, and are able to set 600–820 traps per day. Larger vessels face cost constraints while smaller vessels face operational problems.

Management

The fishery has been managed under Federal jurisdiction with a fishery

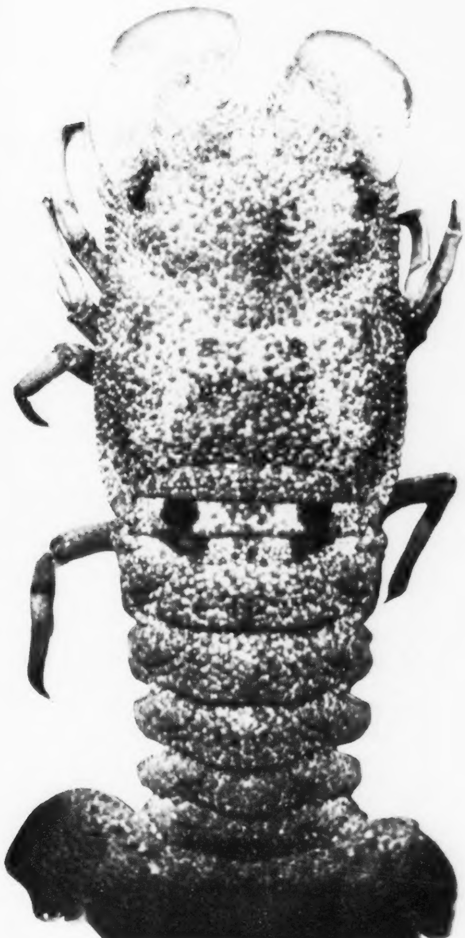

Figure 3.—The slipper lobster, *Scyllarides squammosus*.

management plan (FMP) administered by the Western Pacific Regional Fishery Management Council (WPRFMC) since 1983. Currently the plan prohibits the harvest of slipper lobster (*S. squammosus*) with a tail width of <56 mm and spiny lobster (*P. marginatus*) with a tail width of <50 mm, prohibits the retention of egg-bearing females, requires that all traps have escape vents to reduce handling and release-induced mortality on sublegal lobsters, and mandates that vessels submit logbooks recording daily catch and trapping effort. A decline in CPUE from 1.25 lobster per trap-haul in 1988 to 0.6 in 1990 as well as concerns that vessels from other fisheries in worse condition were considering entering the lobster fishery, motivated the fishermen to work with the WPRFMC to develop a limited entry and harvest quota plan. Further, to protect the spawning biomass of the stock while the plan was being developed the WPRFMC passed emergency regulations to close the fishery for 6 months (May through October, 1991). In March 1992, the lobster FMP was amended to include provisions for a limited entry system for a maximum of 15 vessels, an annual fleet harvest quota, and a closed season from January through June to protect the spawning biomass before the summer spawning. The quota is set to achieve an average CPUE over the fishing season of 1.0 lobster per trap-haul. A preseason quota is set using an estimate of the population size at the end of the previous fishing season and estimates of natural mortality and recruitment. A final quota is set after the first month of fishing based on the CPUE during that month. Information from research surveys can also be used in the quota calculations. Currently, fishermen and managers are considering whether an individual quota would be an improvement over the current fleet quota.

The lobster fishery has sufficient management regulations, which if applied correctly, should make the fishery sustainable and economically profitable. However, environmental factors may result in both considerable annual as well as decadal-scale variation in the exploitable lobster population and hence landings.

The Shrimp Fishery

Deepwater pandalid shrimp are found in some abundance throughout the tropical and subtropical Pacific (King, 1984; Moffitt and Polovina, 1987). In Hawaii, research trapping showed that *Heterocarpus laevigatus* (Fig. 5) and the smaller and more shallow dwelling species, *H. ensifer*, could be readily caught in the depth range 350–825 m in baited traps (Struhsaker and Aasted, 1974). During the past decade there have been two periods when the resource, particularly the more valuable species *H. laevigatus*, has been the target of fishing. In the early 1980's a small trap fishery was initiated around the main Hawaiian Islands. The vessels typically used large, pyramid-shaped traps with a volume of almost 2 m^3, and a large vessel might set up to 50 traps a day (Tagami and Barrows,

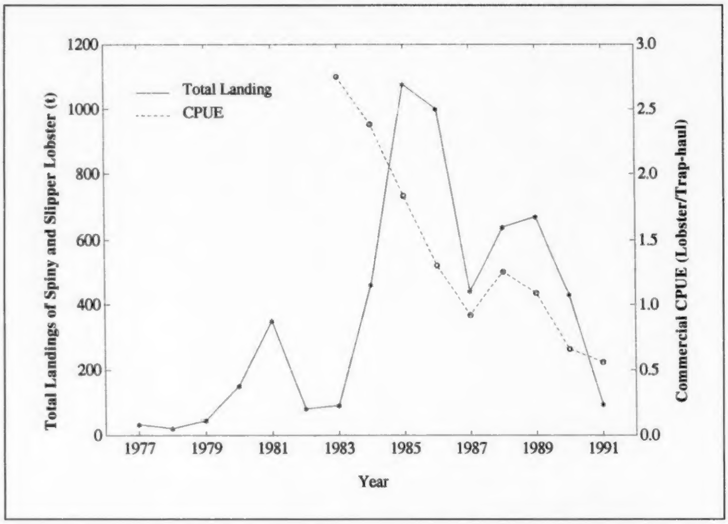

Figure 4.—Total lobster landings and commercial catch per unit effort (CPUE) from the lobster fishery in the Northwestern Hawaiian Islands. Data since 1983 are based on vessel logbooks required under the fishery management plan.

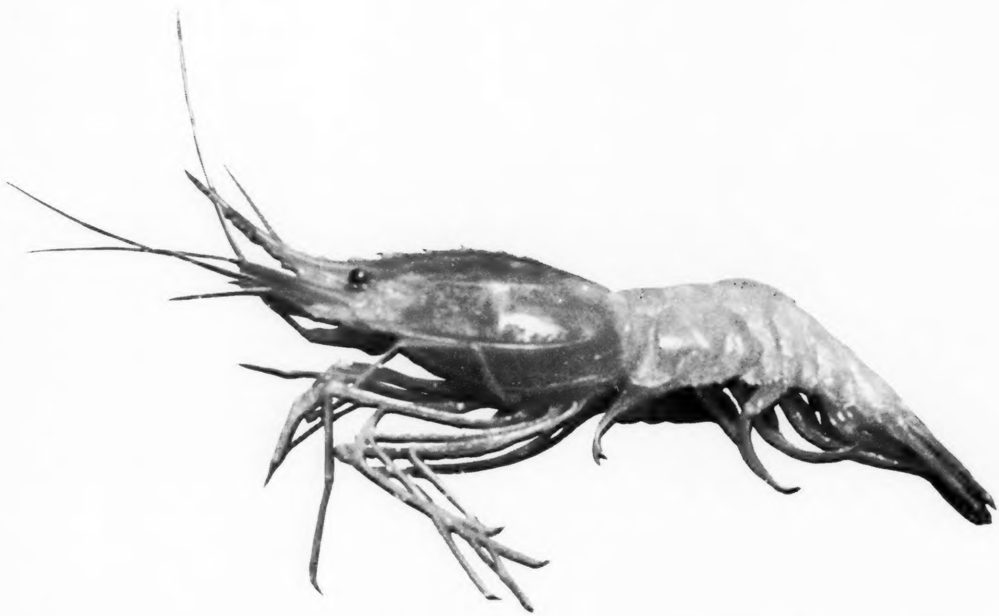

Figure 5.—The deepwater shrimp, *Heterocarpus laevigatus*.

1988). Landings from this fishery peaked in 1984 at over 190 metric tons of *H. laevigatus* with an ex-vessel value of $1.5 million ($7.85/kg) from 7 vessels, 23–40 m in length (Ralston and Tagami, 1992). However by the late 1980's most of the vessels had left the fishery as declining catch rates and the high cost of the deep trapping made the fishery unprofitable. There was a resurgence in the fishery in 1990, when landings of over 100 t were reported, primarily the result of intensive fishing by a single vessel but this level of production was not sustainable at a profitable CPUE[3]. Currently there are no management regulations for this resource.

Recent research has conducted submersible surveys of shrimp densities on different habitats and estimated shrimp biomass from an intensive trapping depletion study (Moffitt and Parrish, 1992; Ralston and Tagami, 1992). The submersible surveys observed that *H. ensifer* tended to group around large anemones and other benthic relief over an otherwise flat, sandy bottom and were very active in the presence of a baited trap (Gooding et. al., 1988; Moffitt and Parrish, 1992). However, *H. laevigatus* were solitary and showed little activity around baited traps. Greater densities of *H. laevigatus* were observed on volcanic than on coralline substrata (Moffitt and Parrish, 1992). The depletion study based on intensive trapping estimated a catchability coefficient which when applied to trapping data around the main Hawaiian Islands estimated an exploitable biomass of *H. laevigatus* of 271 t (Ralston and Tagami, 1992).

While the deepwater shrimp resource may support a very limited local fishery or perhaps periodic heavy pulse fishing, it is unlikely to be the object of heavy sustained exploitation. Initial high catch rates appear to drop rapidly, gear loss is appreciable and costly due to the trapping depths, and markets are not well established.

[3]Commercial Landings, State of Hawaii, Division of Land and Natural Resources, Division of Aquatic Resources, 1990.

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An Ecological Perspective on Inshore Fisheries in the Main Hawaiian Islands

M. KIMBERLY SMITH

Introduction

Regional Geography and Fishing Pressure

The volcanic peaks and platforms that make up the Hawaiian Islands rise from the ocean floor between roughly lat. 19–28° N and long. 155–178° W, giving the archipelago a length of close to 1,500 miles. However, almost all of Hawaii's population and land mass (above sea level) is concentrated on eight islands, located within 300 miles of the southeastern tip of the island chain (Fig. 1). These are the main Hawaiian Islands (MHI), which include Hawaii, Maui, Lanai, Kaho'olawe, Molokai, Oahu, Kauai and Ni'ihau. They are distinguished geologically and for management purposes from the submerged islands and atolls northwest of Kauai (beginning with Nihoa), known as the Northwestern Hawaiian Islands (NWHI).

Accessibility and rates of exploitation of Hawaiian inshore fisheries are determined largely by regional geography. Emergent portions of the NWHI are minimal, are exposed to treacherous northerly storms, and offer only limited freshwater and vegetation. These are some of the reasons the NWHI are largely uninhabited by humans. Travel from populated islands can take from days to weeks, depending on the size and condition of the vessel. Because of the distances involved, commercial fishermen with large vessels are essentially the only participants in NWHI fisheries.

The NWHI are an important breeding and resting ground for monk seals, green sea turtles, and various migratory seabirds whose natural habitat has been disturbed because of human activity in the MHI (Balazs, 1980; Gilmartin et al., 1980; Harrison and Hida, 1980). Most of the inshore area is part of the Hawaiian Islands National Wildlife Refuge (designated in 1909 by President Theodore Roosevelt as a bird refuge), managed by the U.S. Fish and Wildlife Service (USFWS). To maintain a less disturbed environment for threatened and endangered species, recreational and commercial activities (including fishing) are not allowed within the 10–20 fathom isobath of most islands northwest of Kauai (varying with location). Because of this, inshore fisheries in the NWHI are largely unexploited.

Inshore fish and invertebrate resources in the NWHI include many popular MHI species, such as a'ama crab, *Grapsus grapsus*; ahólehóle, *Kuhlia sandvicensis*; striped mullet, *Mugil cephalus*; and moi, *Polydactylus*

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ABSTRACT—A description of fisheries within a depth of 100 fathoms is provided for the eight southeastern-most islands of the Hawaiian Archipelago, known as the main Hawaiian Islands (MHI). These are the inhabited islands of the State of Hawaii and are those most subject to inshore fishing pressure, because of their accessibility. Between 1980 and 1990, an average of 1,300 short tons of fishes and invertebrates were reported annually within 100 fm by commercial fishermen. Total landings may be significantly greater, since fishing is a popular pastime of residents and noncommercial landings are not reported. Although limited data are available on noncommercial fisheries, the majority of this review is based on reported commercial landings.

The principal ecological factors influencing fisheries in the MHI include coastal currents, the breadth and steepness of the coastal platform, and differences in windward and leeward climate. Expansive coastal development, increased erosion, and sedimentation are among negative human impacts on inshore reef ecosystems on most islands. Commercial fisheries for large pelagics (tunas and billfishes) are important in inshore areas around Ni'ihau, Ka'ula Rock, Kauai, and the Island of Hawaii (the Big Island), as are bottom "handline" fisheries for snappers and groupers around Kauai and Molokai. However, many more inshore fishermen target reef and estuarine species.

Two pelagic carangids, "akule," Selar crumenopthalmus, *and "opelu,"* Decapterus macarellus, *support the largest inshore fisheries in the MHI. During 1980-90, reported commercial landings within three miles of shore averaged 203 and 125 t for akule and opelu, respectively. Akule landings are distributed fairly evenly throughout the MHI, while more than 72% of the state's inshore opelu landings take place on the Big Island. Besides akule and opelu, other important commercial fisheries on all the MHI include those for surgeon, soldier, parrot, and goatfishes; snappers; octopus, and various trevallies. Trends in reported landings, trips, and catch per unit effort over the last decade are outlined for these fisheries. In heavily populated areas, fishing pressure appears to exceed the capacity of inshore resources to renew themselves. Management measures are beginning to focus on methods of limiting inshore fishing effort, while trying to maintain residents' access to fishing.*

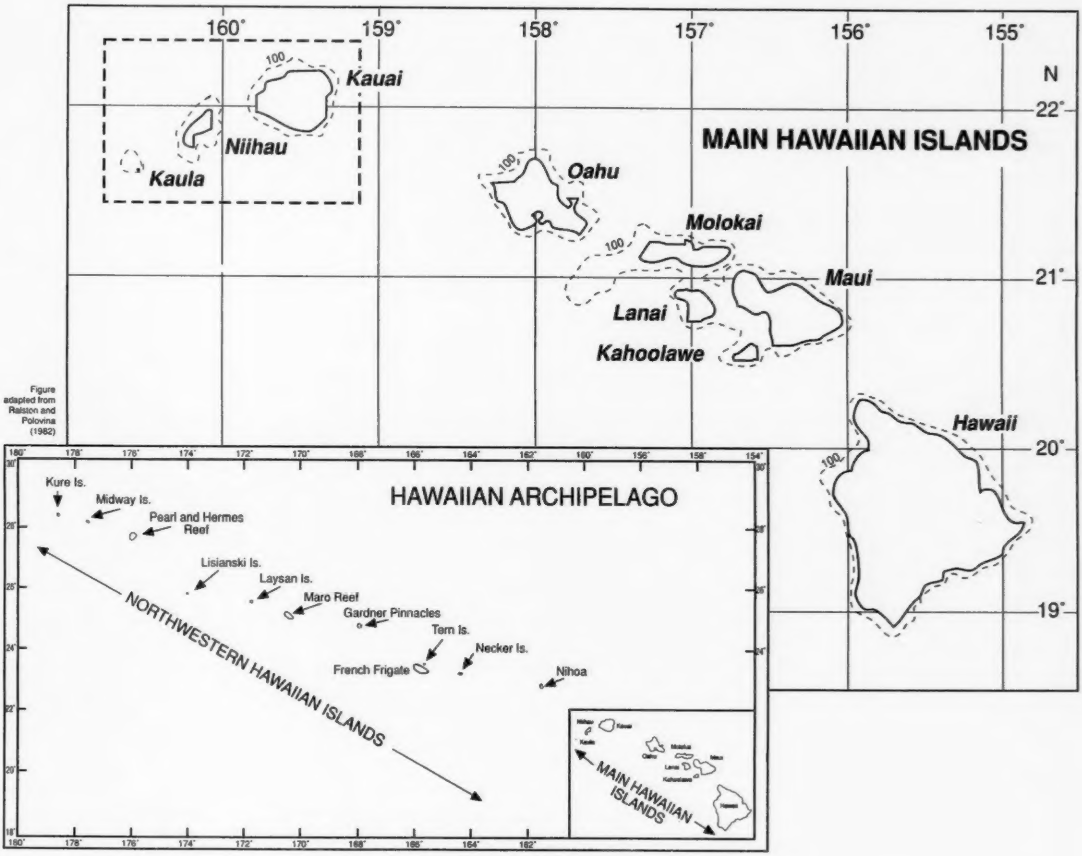

Figure 1.—Hawaiian Archipelago showing main Hawaiian islands.

sexfilis (Okamoto and Kanenaka, 1984). Spiny lobster, *Panulirus marginatus*, various eteline and lutjanid snappers, jacks, groupers, and large pelagic fishes are found slightly farther from shore (Uchida and Uchiyama, 1986), just as is seen in the MHI. These and other inshore fisheries in the MHI, where they are harvested, are the subject of this review.

Climate, Coastal Topography, and Inshore Fishery Habitats

Inshore fisheries will be defined for this review as those within the 100–fm contour. This arbitrary boundary is found within three miles of shore throughout most of the MHI. Its correspondence with the offshore limit of state waters is convenient, although many inshore species migrate freely across the three-mile boundary. Normally the continental shelf is used as a guideline for the limit of inshore fisheries; however, these volcanic islands have no continental shelf. Gosline and Brock (1976) also selected the 100–fm isobath as an outer boundary, justifying this in part because it was the maximum depth fished by traps and handlines at that time. Modern hydraulic gurdies have extended the depth limit for fishing somewhat, but 100 fm is still a reasonable limit for small boat inshore fisheries (Squire and Smith, 1977).

Depth profiles, climate, and terrestrial influences are important determinants of the distribution of inshore fisheries in the MHI. The importance of coastal topography and hydrography may be accentuated by Hawaii's relative isolation in the northern tropical Pacific. The attraction of some pelagic species toward land formations (Murphy and Shomura, 1972) may also enhance inshore fishing opportunities.

The climatic pattern, which affects the distribution of terrestrial and aquatic communities throughout the MHI and most of the northern tropical Pacific is determined by prevailing trade winds. Wind-born weather fronts lose some of their moisture in passing over the mountainous portions of islands in this region. Thus, windward (northeastern) slopes have higher rainfall than leeward (southwest-facing) slopes. Because of this, windward embayments tend to support more estuarine fisheries than leeward areas.

Although high rainfall, erosion, and sedimentation are antagonistic to the survival of healthy corals, the coastal shelf also sustains fringing and patch reefs in windward regions. These habitats support rock- and crevice-dwelling organisms, such as octopus, crabs, and lobsters. The balance between the degree of protection from wind and waves, the amount of rainfall and sedimentation, and the availability of shallow shelf influences the extent of reef development in windward and leeward areas.

There are few stream-fed estuaries in Hawaii. The most important freshwater input to inshore areas may well be through groundwater (Carlquist, 1980). Wherever sources of freshwater meet the ocean (particularly in embayments), fish such as the Hawaiian anchovy or "nehu," *Encrasicholina purpurea*; round herring, *Etrumeus micropus*; and gold spot herring, *Herklotsichthys quadrimaculatus*; return seasonally to spawn (Williams and Clarke, 1983; Clarke, 1989). More commonly, Hawaiian fishes use estuaries as feeding and nursery areas, and may spawn offshore (Clarke, 1991). Fishes which feed in Hawaiian estuaries include mullet, *Mugil cephalus*; Hawaiian flagtail, *Kuhlia sandvicensis*; bigeye scad, *Selar crumenopthalmus*; and various species of snappers and trevally. Schools of adults and juveniles are targeted by fishermen as they enter and leave embayments.

Substrate, current, shelter, and food preferences of Hawaiian fishes are among other factors that separate species guilds and fisheries in relation to habitat (Gosline and Brock, 1976; Squire and Smith, 1977). Despite its narrow shelf, a wide variety of submerged habitats can be found around the MHI. The lagoons, bays, and beaches that surround these islands vary in composition from sand and mud to rock and coral. Sandy corridors, rocky slopes, and outcroppings are inhabited by large carangids, snappers, and groupers which are harvested with bottom "handlines" (Ralston and Polovina, 1982). Kona crabs, *Ranina ranina*, are also caught in these areas (Onizuka[1]). Schools of goatfishes, small carangids, and the introduced blueline snapper or ta'ape, *Lutjanus kasmira*, are common closer to shore in open and embayed habitats.

Hawaiian reefs support diverse and colorful communities of tropical fishes, invertebrates, and marine algae, which vary as a function of the depth, exposure, and three dimensional relief of their habitat (Fielding and Robinson, 1987; Oishi[2]). Reef fishes and invertebrates include lobsters, crabs, octopus, surgeonfishes, parrotfishes, and cryptic nocturnal species such as glasseyes (*Heteropriacanthus cruentatus* and other priacanthids), soldierfishes, *Myripristis* spp., and squirrelfishes, *Sargocentron* spp. Many of these are targeted by pole-and-line fishing, trapping, or spearing; nets are also employed along the reef flats and edges, yielding much larger catches per gear-unit.

The Main Hawaiian Islands

The MHI, or "high islands" (islands above sea level), represent the younger portion of the Hawaiian Archipelago. Because they have emerged in relatively recent geologic time, these islands have less well-developed fringing reefs and have not subsided as far below sea level as the NWHI. The MHI form natural geographic groups, unified by shared channels and portions of interisland shelf (Fig. 1), which include: 1) Ni'ihau, Ka'ula Rock, and Kauai (the Kauai Complex), 2) Oahu, 3) Molokai, Maui, Lanai, and Kaho'olawe, (the Maui Complex), and 4) Hawaii (the Big Island). These island platform groups are meaningful for the discussion of inshore fisheries because of the dispersal characteristics of Hawaiian fishes (Jordan and Evermann, 1905; Gosline and Brock, 1976). Fishing activity, navigable sea conditions, and movements of fishermen are closely tied to shallow coastal waters and thus are based within shared portions of coastal shelf (Squire and Smith, 1977; PAC[3]). County designations throughout the state also reflect these associations. Kauai and Ni'ihau are in Kauai County; Oahu is in Honolulu County; Lanai, Molokai, Maui, and Kaho'olawe are in Maui County; and the Island of Hawaii makes up its own county.

The Kauai Complex

Kauai, Ni'ihau, and Ka'ula Rock (a small peak southwest of Ni'ihau) are located at the northwestern corner of the MHI, separated from the other islands by the 72–mile-wide Kauai Channel between Kauai and Oahu. Kauai is dominated by a single mountainous mass, cut by steep slopes and ridges, which occupies most of its central and western sectors. Most of Kauai's coastline has lush vegetation, high rainfall (600–700 inches annually on some parts of the island), strong currents, and precipitous drop-offs to oceanic depths. The windward coasts are shaped by seasonal flooding and stream input, providing avenues along which endemic gobies enter and leave their oceanic larval phase (Radtke et al., 1988; Kinzie, 1990). Intensive spawning and migration events stimulate inshore fisheries. During the breeding season, Kauai's northeastern to southern shores are a popular area for recreational fishermen targeting the gobiid *Awaous stamineus* (known as 'o'opu nakea). Although reef fishes are seen all around the island, the southwestern coast shows a stronger oceanic influence and supports more reef and coastal pelagic fisheries, including those for bigeye and mackerel scads, goatfishes, surgeons, and squirrelfishes. Thrownetting and spearfishing are also prevalent on Kauai's leeward coast.

Ka'ula Rock and Ni'ihau, with steep nearshore slopes are drier than Kauai. All three islands provide habitat for snappers and groupers, captured by bottom hook-and-line fishing (referred to as "handlining," although hydraulic gurdies are used). Ni'ihau also supports a significant fishery for Kona crab

[1]E. W. Onizuka. 1972. Management and development investigations of the Kona crab, *Ranina ranina* (Linnaeus). Final Report to Div. Aquatic Resources, Dep. Land and Natl. Resources, State of Hawaii, 28 p.

[2]F. Oishi. 1992. Hawaii's marine life conservation districts. Div. Aquatic Res., Dep. Land and Natl. Resources, State of Hawaii, 18 p.

[3]Pacific Analysis Corporation. 1984. Status of commerical fishing in the State of Hawaii. U.S. Army Eng. Div., Pac. Ocean Corps, Ft. Shafter. Prepared by PAC, 68 p.

(Onizuka[1]). Depths of 100 fm are reached within two miles of the shore of all three islands that make up the Kauai Complex, broadening to within 3–5 miles on the north shore of Kauai.

Oahu

Seventy-two miles southeast of Kauai and twenty-six miles north of Molokai (across the Kaiwi Channel), Oahu is home to about 75% of the state's 1.3 million inhabitants (DBEDT, 1990). Having sustained the largest population for more than a century, it has experienced the highest levels of fishing pressure and other human impacts of all the Hawaiian Islands. The impacts of human development on fish populations along Oahu's heavily populated coast have been noted since the turn of the century (Jordan and Evermann, 1905). Artificial islands and airstrips have been built over reefs, bays, and sandbars on Oahu's leeward side; commercial and private piers, loading docks, high-rise hotels, and heavily populated beaches have overrun the natural shoreline. Dynamite was used to carve shipping channels into the reefs of Kaneohe Bay, on the windward coast, and the resulting coral rubble was placed into various landfills along its shoreline (Devaney et al., 1982). Coastal sites invaded by urban development include many ancient Hawaiian fishponds. In spite of congestion, residents can be found fishing from shore at all times of the day and night, especially along the less developed windward coast. Fishermen using light tackle line the windward shore during summer runs of oama and hahalalu (juvenile goatfish and bigeye scad).

The coastal shelf around Oahu is broader than that of the Kauai Complex, particularly at its prominent points. However, the 100–fm contour is still within three miles of shore in most areas. Bottom handlining, spearing, and trapping are among fisheries which depend on Oahu's relatively wide coastal shelf. Surround net and gill net fishing also take place on this shelf in embayments and along the edges of reefs.

Parallel mountain ranges, running northwest to southeast, determine Oahu's pattern of leeward and windward climate. Its northern and northeastern shores are strongly influenced by stream, surface, and groundwater input, seasonal storms, flooding, and high waves. Windward fisheries include several for estuarine species, such as mullet, crabs, carangids, octopus, sardines, and anchovies. The climate is generally drier on the southwestern side of the island, supporting more typically marine fisheries. However, Pearl Harbor in the middle of Oahu's leeward shore is the state's largest estuary.

Together, Pearl Harbor and Kaneohe Bay represent over 80% of true estuarine habitat in Hawaii. Kaneohe is a windward embayment containing a sandbar and many patch and fringing reefs. A unique mixture of corals and sediments, it has received decreasing amounts of fresh water and increased sediments over the years, owing to deforestation, erosion, and diversion of streams and groundwater to the leeward (more populated) side of the island. Despite decreased freshwater input, Kaneohe Bay is affected by seasonal floods which damage its coral reefs. Freshwater and sediment loading during floods has been intensified by channelization of streams and steeply graded urban development (Devaney et al., 1982; Gordon and Helfrich, 1970; OSP[4]). Freshwater input to Pearl Harbor has also decreased over the years. Together with marine pollution, this may have diminished its populations of estuarine fishes, such as mullet and certain carangids (Smith et al., 1973; Kimmerer and Durbin, 1975). Regardless of human impacts, both Pearl Harbor and Kaneohe Bay still support two of Oahu's largest and most diverse fisheries.

The Maui Complex

On the southeast side of the Kaiwi Channel, Maui, Molokai, Lanai and Kaho'olawe form parts of a unified platform with a maximum depth of <100 fm. The Maui Complex has the widest coastal shelf of all the island platform groups. In some places (notably Penguin Bank), the 100–fm isobath is found over 30 miles from shore. The shallow, protected channels and beaches between islands provide a nesting and feeding ground for marine turtles, and a breeding and nursery ground for humpback whales. The channels and broad shelf are also a favorite fishing ground for full-time and experienced part-time fishermen, the latter known locally as the "weekend warriors."

Maui's dominant geological features are two volcanic peaks, Pu'u Ula'ula (Red Hill, on eastern Maui) and Pu'u Kukui (Candlenut Hill or the West Maui Mountains), united by a narrow land bridge. The double-mountain formation creates two natural embayments, windward Kahului and leeward Ma'alaea Bay. Maui's windward side is a lush, green agricultural area. Its leeward slopes are dry (but fertile) volcanic soil. Coastal soils have been heavily eroded by farming and development, as is common throughout the MHI. Spearfishing, surround and gill netting are the principal inshore methods used on the windward coast; while throw netting and handlining are popular on Maui's leeward shore. Due west of Ma'alaea Bay is Molokini Shoal, a unique and abundant area which is protected as a (State) Marine Life Conservation District (MLCD).

Molokai, the northernmost member of the Maui group, is also a double island. Its peaks, (western) Pu'u Nana and (eastern) Kamakou, are less than half the height of the mountains on Maui, giving the island a relatively dry climate and providing a less heterogeneous coastal habitat. Penguin Bank, on the western end of Molokai, is the most extensive shallow shelf area in the Hawaiian Islands. This bank supports a productive bottom "handline" fishery for snappers and groupers (Ralston and Polovina, 1982) and extensive net harvests of Kona crab (Onizuka[1]). Molokai is known for its numerous Hawaiian fishponds, many of which are now either partially or fully submerged. With fewer inhabitants and a closer adherence to traditional fishing methods than is seen on

[4]Office of State Planning. 1992. Kaneohe Bay master plan. Rep. of Kaneohe Bay Master Planning Task Force. OSP/Coastal Ocean, Reef and Island Advisors, Ltd., 171 p.

more populated islands, Molokai has fewer problems from overfishing of inshore habitats.

Kaho'olawe, now uninhabited, was taken over by the U.S. Navy in 1941 and used as a training area for more than 50 years (Clark, 1985). In 1968, the Navy began to reopen nearshore areas to fishermen and boaters. The island is gradually being reclaimed and debris (including monofilament line, plastic garbage, and unexploded ordnance), which accumulated during the military occupation, is being removed to eliminate the hazard to humans and marine life in the area.

Lanai, a small island west of Maui, is dedicated to agriculture. With the exception of the state harbor at Manele Bay, its entire coastline above the vegetation zone is private property. Access is mainly limited to resident workers and their guests. A few partially submerged Hawaiian fishponds are found on Lanai's eastern coast, where the fringing reef is farthest from shore. Quiet beaches on the western side of the island provide a nesting ground for green sea turtles. The southwestern shore supports another type of marine life refuge, the Manele-Hulopo'e MLCD.

Hawaii, the "Big Island"

The Island of Hawaii, at the southeastern end of the Hawaiian Archipelago (across the Alenuihaha Channel), is known to residents as the "Big Island." Still volcanically active, the Big Island is dominated by two large dome volcanoes (Mauna Loa and Mauna Kea), and a few smaller ranges and craters. New beaches can be created in days or weeks on the southeastern coast, as a consequence of volcanic activity. The 100–fm isobath is found well within a mile of shore, from Kealakekua Bay on the western side and around the southern tip of the island to Cape Kumukahi. The coastal shelf widens to within 2–5 miles along the northern coast, from Cape Kumukahi to Kealakekua.

Wind and weather are particularly important along Hawaii's northeast shore, which receives year-round high rainfall, and periodic storm and seismic waves (or "tsunamis"). Windward Hilo Harbor supports extensive recreational and commercial fisheries for sardines, 'ama'ama (mullet), ahólehóle (Hawaiian flagtail), hahalalu (young bigeye scad), kuahonu crab, *Portunus sanguinolentus*; and Samoan crab, *Scylla serrata*[5]. Reef fishes are also caught on the open coast in this region.

The repercussions of land-based human activities in the Big Island's windward fisheries have been noted since the effluents of the sugar industry made streams and inshore areas uninhabitable to some fishes (Welsh[6]). These impacts have been mitigated to a certain extent over the years (Grigg, 1972, 1985), but have by no means been eliminated. Erosion and freshwater input via streams and groundwater influence nearshore ecology dramatically. The brown halo seen along the windward coast during rainy periods is an index of the magnitude of coastal erosion. Natural erosion has been intensified by the loss of forested areas to cattle ranching and agriculture. Additional environmental concerns for the Big Island's windward coast include those from toxics (DOH, 1981; Hallacher et al., 1985), sewage (Ambrose and Johnson, 1987), privately owned septic systems (Dudley et al., 1991), and petroleum derivatives from small and large vessels.

In contrast to the lush green valleys and raging rivers of the windward side, the Big Island's leeward (Kona) coast is flatter and drier and has more developed coral reefs. The inshore dropoff is particularly steep on the Kona Coast. Deep inshore waters and currents favorable to large pelagic fishes make it a preferred site for trollers and deep pelagic handline fishermen, who catch tunas, mahimahi, *Coryphaena hippurus*; and billfishes in this region. However, the most prominent inshore fisheries are those for smaller coastal pelagics, such as mackerel scad, *Decapterus macarellus*; and bigeye scad, *Selar crumenopthalmus*. Reef fish harvests of surgeon and soldierfishes are also significant in this area.

Available Data

Commercial Fisheries

Although anecdotal information is available, the only consistent long-term source of data on Hawaii's fisheries is the commercial landings database maintained by the State Division of Aquatic Resources (DAR, formerly the Division of Fish and Game). Anyone who catches and sells even one fish is considered a commercial fisherman and is required to report his or her landings and fishing effort on a monthly basis. The location of fishing activity is referenced to numbered geographic areas from the Commercial Fisheries Statistical Charts (DAR[7]), which are given to fishermen with catch report forms.

Despite legal reporting requirements, in practice there is considerable nonreporting. In the past, actual commercial landings may have been as much as double the amount reported for some species. Improved follow-up measures to track down licensed fishermen who fail to report have significantly increased the proportion of licensed commercial landings registered since 1989; however, other commercial fishermen remain unlicensed and commercial landings are still underestimated. Methods of improving the accuracy and completeness of commercial landings data are constantly under review (DAR[8]; Kasaoka[9]). Regional, seasonal, and short-term annual trends in these data are considered reliable and provide a plausible index of differences in commercial landings and

[5]J. Kahiapo and M. K. Smith. In review. Recreational fishing survey of Hilo Bay: 1985–1990. Div. Aquatic Resources, 75 Aupuni St., Rm. 220, Hilo, Hawaii 96720, 41 p.

[6]J. P. Welsh. 1949. A preliminary report to the Division of Fish and Game Bait Program. Section 1. Summary of field work with special reference to Hilo Harbor nehu scarcity. Fish. Progr. Rep., Div. Fish Game, Bd. Comm. Agr. Forest, Hawaii 1(1), 25 p.

[7]Div. Aquatic Resources, State of Hawaii. 1990. Commercial fisheries statistical charts. Div. Aquatic Resources, Dep. Land and Natl. Resources, Charts A-H.

[8]Div. Aquatic Resources, State of Hawaii. 1984. Hawaii fisheries statistics design study. Div. Aquatic Res., Dep. Land and Natl. Resources, 187 p.

[9]L. D. Kasaoka. 1991. Revising the State of Hawaii's commercial fish catch reporting system. Final Report to Div. Aquatic Resources, Dep. Land and Natl. Resources, 466 p.

fishing activity. However, recorded data would not represent total landings even if 100% reporting could be achieved, because there is no law to require recreational catches to be reported.

Noncommercial (Recreational and Subsistence) Fishing

Hawaii is a state of fishermen and both recreational and "subsistence" landings are an important consideration. Actual "subsistence" fishing is rare. Most noncommercial fishermen fish either for enjoyment or to put food on the table, but do not rely on fishing as a source of food. Many are either retired or have a full-time job. Hawaii is one of the few U.S. coastal states which does not require a saltwater recreational fishing license. Because there are no recreational permitting or reporting requirements, it is difficult to estimate the number of recreational fishermen in Hawaii or their landings. Surveys indicate that 19–35% of residents fish (Hoffman and Yamauchi, 1972; USFWS, 1988). Estimates of recreational anglers alone were above 187,000 in the early 1980's (DAR[10]), as opposed to about 4,000 licensed commercial fishermen. Lal and Clark (1991) cited the State Department of Transportation and the U.S. Army Corps of Engineers as a source for an estimated 12,690 "personal boats," of which approximately 74% were engaged in fishing as their primary activity.

Recreational fishermen may outnumber commercial fishermen significantly, but per-trip landings are considerably lower. The difficulty in interpreting trends in total landings is compounded by differences in fishing gears and species targeted recreationally vs. commercially (SMS Research[11]; Samples and Schug[12]; Meyer Resources, Inc.[13]). Shoreline fishing with pole and line, trolling, spearfishing, throw netting, and crab netting are all popular activities of noncommercial fishermen. Surveys at Hilo, on the Big Island, show that 40–70% of shoreline fishing is conducted either with rod and reel or handpole (a bamboo pole without a reel) (Kahiapo and Smith, unpubl. data). This can be contrasted with an estimated 0.5% of commercial fishermen using light tackle in this area. Skillful fishermen, averaging 40–60 years of age, spend hours fishing patiently for 'ama'ama, hahalalu, crabs, and ahólehóle at Hilo and other areas throughout the state (Table 1 provides local and common fish names).

Differences in fishing areas, access methods, and target species of recreational fishermen mean their contribution to the total weight and species composition of landings must also be different. These differences make it impossible at present to interpret overall trends in landings and catch rates for species taken jointly by the recreational and commercial sectors. An independent estimate of recreational landings is needed. Only fragmentary information is presently available, but an effort is in progress to improve the data.

In the last 5–8 years, the DAR and the National Marine Fisheries Service (NMFS) have begun developing methods of estimating total landings through port and shoreline fishing (or "creel") surveys. Creel surveys involve field observation and interviews of recreational and commercial fishermen. Results of a pilot port-of-landing survey for greater Oahu show that some gears and species which are insignificant in commercial landings become important when total landings are considered (Hamm and Lum[14]). Inshore methods which are widely dispersed along the shoreline, such as spearing (for octopus and reef fishes), trapping (for small fishes), and handpicking (for marine algae) are particularly difficult to sample and may not show up at all in either commercial catch reports or port-of-landing surveys (Everson[15]). Shoreline creel surveys are now being conducted in several locations, including Kaneohe Bay (Everson[15]) and Waikiki (Yamamoto[16]; DLNR, 1992), Oahu; Hilo Bay, Hawaii (Kahiapo and Smith, unpublished data); and Hanalei and Nawiliwili Bays, Kauai. Fishery scientists may rely increasingly on information obtained through creel surveys to assist in interpreting reported data for estimates of overall landings for the state. Where data are available, recreational fisheries are included in the present discussion. However, it is important to keep in mind that the following summaries are based primarily on reported commercial landings.

Sport Fishing

Besides residents, Hawaii supports an extensive gamefish charter boat industry catering to visitors. Samples et al.[17] estimated that 73,780 passenger-trips per year were completed during 1982, capturing about 2.2 million pounds of fish and $8.1 million in total revenue. It is common for the sport catch to become the property of the vessel and be sold by the captain. Charter boat operators are considered to be commercial fishermen (Hawaii Revised Statutes §189–2) and thus are required by law to submit catch reports

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[10]Div. Aquatic Resources, State of Hawaii. 1981. Management of Hawaii's coastal zone: Living marine resources. Div. Aquatic Resources, Dep. Land and Natl. Resources, 95 p.

[11]SMS Research. 1983. Experimental valuation of recreational fishing in Hawaii: Final Report. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-83–11C, 43 p.

[12]K. C. Samples and D. M. Schug. 1985. Charter fishing patrons in Hawaii: A study of their demographics, motivations, expenditures and fishing values. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-85–8C, 95 p.

[13]Meyer Resources, Inc. 1987. A report on resident fishing in the Hawaiian Islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-87–8C, 74 p.

[14]D. C. Hamm and H. K. Lum. 1992. Preliminary results of the Hawaii small-boat fisheries survey. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-92–08, 35 p.

[15]A. Everson. 1991. Fishery data collection system for fishery utilization study of Kaneohe Bay: One year summary report. Hawaii Inst. Mar. Biol. NMFS job report to Div. Aquatic Res., Dep. Land and Natl. Res., 14 p.

[16]M. Yamamoto. 1990. Annual job progress report. Federal aid in sportfish restoration activities. Statewide Marine Research and Surveys Project F-16–R-15. Monitoring of Waikiki-Diamondhead FMA.

[17]K. C. Samples, J. N. Kusakabe, and J. T. Sproul. 1984. A description and economic appraisal of charter boat fishing in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-84–6C, 130 p.

Table 1.—Inshore commercial species by habitat, gear, and fishing method.

Habitat	Fishing gear or method	Scientific name	Local name	Common name	Percent weight[1]
Shelf, slope and channel:	Bottom handline	*Etelis coruscans*	Onaga	Red snapper	0.79
Rocky to sandy bottoms		*Etelis carbunculus*	Ehu	Red snapper	0.23
		Pristipomoides filamentosus	Opakapaka	Pink snapper	1.54
		Pristipomoides sieboldii	Kalekale	von Siebold's snapper	0.14
		Aprion virescens	Uku[2]	Grey snapper	1.33
		Seriola rivoliana	Kahala[2]	Amberjack	0.53
		Epinephelus quernus	Hapu'upu'u	Seale's grouper	0.13
		Lutjanus kasmira	Ta'ape[2]	Blue-line snapper	2.80
		Heterocarpus laevigatus	Ono Shrimp	Deepwater shrimp	1.39
Coastal pelagic:	Surround net	*Selar crumenopthalmus*	Akule/Hahalalu[3]	Bigeye scad	28.92
Interisland channels and	Purse seine	*Decapterus macarellus*	Opelu	Mackerel scad	17.82
inshore areas right outside	Pelagic handline	*Makaira mazara*	A'u	Blue marlin	0.94
the reef	Trolling	*Tetrapturus audax*	A'u	Striped marlin	0.17
	Pole and line	*Xiphias gladius*	Shutome	Broadbill swordfish	0.18
	Palu'ahi (using fish chum)	*Thunnus albacares*	'Ahi	Yellowfin tuna	9.37
	Ikashibi (using squid as bait)	*Thunnus alalunga*	Tombo	Albacore	0.11
		Katsuwonus pelamis	Aku	Skipjack tuna	1.65
		Acanthocybium solandri	Ono	Wahoo	2.29
		Coryphaena hippurus	Mahimahi	Dolphinfish	1.05
		Euthynnus affinis	Kawakawa	Bonito	0.22
		Sphyraena barracuda	Kaku	Barracuda	0.10
		Sphyraena helleri	Kawelea	Heller's barracuda	0.27
		Elagatis bipinnulatus	Kamanu	Rainbow runner	0.12
Reef[6] and rocky:	Handline	*Mulloides flavolineatus*	White/Green Weke	Yellowstripe goatfish	2.39
Open coast predominantly	Spear	*Mulloides pflugeri*	Weke-ula	Pfluger's goatfish	0.71
marine areas	Traps	*Parupeneus porphyreus*	Kumu	Whitesaddle goatfish	0.57
Juveniles in embayments	Various nets	*Parupeneus multifasciatus*	Moano	Manybar goatfish	0.39
		Pseudupeneus cyclostomus	Moano Kea	Blue goatfish	0.15
		Acanthurus dussumieri	Palani	Eyestripe surgeonfish	1.15
		Acanthurus triostegus	Manini	Convict tang	0.60
		Acanthurus xanthopterus	Pualu	Yellowfinned surgeon	0.30
		Naso unicornis	Kala	Unicornfish	0.69
				Other surgeonfishes	0.39
		Myripristis berndti & others	U'u (Menpachi)	Soldierfishes	2.07
		Scarus spp.[4]	Uhu	Parrotfishes	1.96
		Atule mate	Omaka	Yellow-tailed scad	2.97
		Caranx ignobilis	White (Ulua/papio)	White trevally[5]	
		Caranx melampygus	Omilu (Ulua/papio)	Bluefin trevally[5]	
		Caranx sexfasciatus	Ulua Menpachi	Bigeye trevally[5]	
		Carangoides orthogrammus	Papa (Ulua/papio)	Yellowspot trevally[5]	
		Gnathodon speciosus	Pa'opa'o	Striped trevally[5]	
		Priacanthus meeki and *Heteropriacanthus cruentatus*	Aweoweo	Red bigeye	0.40
		Bodianus bilunulatus	A'awa	Blackspot wrasse	0.17
		Octopus cyanea	He'e (Tako)	Octopus	1.46
Embayments[6] and estuaries:	Gill net	*Mugil cephalus*	'Ama'ama	Striped mullet	0.42
Including sand, mud, and	Surround net	*Polydactylus sexfilis*	Moi	Threadfin	0.16
patch reef habitats	Paipai net	*Chanos chanos*	Awa	Milkfish	0.09
	Spearing	*Elops hawaiensis*	Awaawa	Ladyfish/Ten pounder	0.05
	Handpicked	*Kuhlia sandvicensis*	Ahólehóle	Hawaiian flagtail	0.33
	Handline	*Albula vulpes*	'O'io	Bonefish	0.58
	Pole and line	*Ranina ranina*	Kona Crab	Spanner crab	0.56
	Casting and spinning	*Portunus sanguinolentus*	Kuahonu Crab	White crab	0.29

[1] Percent weight = mean annual percent (by weight) of commercial landings reported between 1980–90 to the DAR in required Commercial Fish Catch Reports.
[2] Uku, kahala, and ta'ape come in quite close to shore as juveniles and adults.
[3] Adult and juvenile bigeye scad are referred to as "akule" and "hahalalu", respectively. Residents think of the two as distinct and report catches of each separately, as if they were different species.
[4] Parrotfishes captured are mainly *Scarus perspicillatus* and *Scarus sordidus*.
[5] The five species of trevallies listed make up more than 90% of "ulua/papio" landings. Omaka landings were also grouped as uluas since their juveniles may not always be distinguished in catch reports. Adult trevally and other jacks are referred to generally as "ulua"; juveniles as "papio". Kahala landings may also be placed into this group as juveniles because of their similar appearance, but they are separated in this table because of differences in adult habitat. It should be noted that the size at which fish become designated "ulua", rather than "papio" varies from island to island.
[6] There is some overlap in distribution between species listed under "reef" and "estuarine/embayment" habitats. Reefs and their fauna may also be found within embayments and estuaries in Hawaii.

(HRS §189–3). Thus, charter boat landings should be included in reported commercial data.

Inshore Species

Table 1 summarizes local and common names of the principal inshore fishes as a function of depth and habitat. These 47 species represent 91% (by weight) of the state's inshore commercial landings. Individual reef species weigh a fraction of the average for coastal pelagics. Therefore, the weight of landings increases significantly in areas where large pelagic species are caught close to shore (such as on the Kona Coast). Landings in other areas represent a much larger number of organisms and many more hours of fishing effort. Unfortunately, available data do not allow an in-depth evaluation of mean size or numeric abundance, since fishermen often report only the number of pounds caught (most species are sold by weight).

Reef species make up a relatively small fraction of the total weight of

landings, but market preferences increase the economic value of the reef catch. Goatfishes, such as kumu, *Parupeneus porphyreus*, and moano kali (or moano kea, *Parupeneus cyclostomus*), are targeted with traps and spears by inshore fishermen and sell for 2–6 times the price of other goatfishes, depending on the season. Prices for moano kali are the highest because these fish inhabit deeper water, making them more difficult to target.

Reported inshore landings by island platform groups (Table 2) illustrate the most important regional trends in weight and relative abundance of the top ten species in each area. Many species that are major constituents of inshore landings are also captured in significant numbers farther from shore. Because of their high mobility, the assessment and management of these stocks rely on collaboration between State and Federal agencies. Areas in the mid-MHI (Oahu and the Maui Complex), with more developed inshore shelf, fringing and patch reefs, sustain a larger proportion of landings of reef, shelf, and crevice-dwelling species, such as kumu, weke, u'u, ta'ape, palani, uhu, and he'e. The steep coastal slopes and swift currents of the Kauai Complex and the Big Island are a more suitable habitat for inshore pelagic species.

Akule, *Selar crumenopthalmus*; and opelu, *Decapterus macarellus*, landings rank within the top ten fisheries on all islands. From 1980 to 1990, reported commercial landings within three miles of shore averaged 203 and 125 tons for akule and opelu, respectively. Akule (bigeye scad) are the most productive inshore fishery throughout the MHI, except on the Big Island where more opelu (mackerel scad) are caught. Akule are captured with surround nets, made of either nylon or monofilament line (DLNR, 1992). Hoop nets are effective for catching opelu, which dive deeper when startled. Both species are also captured with hook and line. Night jigging with flies for akule and opelu on dark nights or during the new moon, using a small light to attract the fish (Kawamoto[18]), is extremely popular on all islands and among residents of all ages. Either a rod and reel or a simple bamboo "handpole" can be used.

Figures 2 and 3 show regional trends in landings of opelu and akule, respectively, from 1980 to 1990. More than 72% of the state's inshore opelu landings takes place on the Kailua-Kona Coast of the Big Island (Fig. 2). Therefore, trends in opelu landings are dominated by the success of the Big Island fishery. Akule landings (Fig. 3) are distributed fairly evenly throughout the MHI but are greatest on the Kailua-Kona Coast, at Ma'alaea Bay (on Maui) and Waianae (Oahu). Both fisheries have shown cyclical changes in abundance over the past 11 years, with peaks in 1983 and 1989. Changes in catch rates (CPUE, pounds/trip) are primarily responsible for the observed annual differences in catch, presumably because of actual changes in abundance of these highly mobile species in inshore areas. This trend is much stronger for the akule fishery. Regional trends in landings also vary somewhat from year to year (Fig. 2, 3). This is partly due to differences in seasonal migration patterns of the fishes around each island platform group and partly because of movements of a few large purse seiners.

Table 2.—Mean annual landings (short tons) reported for 1980–90 by geographic region for Hawaii's principal inshore commercial species.

Island platform group	Principal Species[1] (descending order by weight of inshore landings): Local name	Scientific name	Mean annual tons[2]	Spp. freq.[3] (%)
Kauai complex	Akule/hahalalu	*Selar crumenopthalmus*	48.98	13.8
	'Ahi (yellowfin)	*Thunnus albacares*	15.71	7.4
	Opelu	*Decapterus macarellus*	10.89	2.8
	Ono shrimp	*Heterocarpus laevigatus*	7.45	0.1
	Ta'ape	*Lutjanus kasmira*	5.69	3.5
	White/green weke	*Mulloides flavolineatus*	3.99	3.2
	U'u	*Myripristis* spp.	3.58	5.2
	Ulua/papio	Primarily *Caranx* spp.	3.55	7.8
	Ono	*Acanthocybium solandri*	3.18	4.2
	Uku	*Aprion virescens*	2.36	3.3
Oahu	Akule/hahalalu	*Selar crumenopthalmus*	67.40	11.9
	Opelu	*Decapterus macarellus*	18.97	6.8
	White/green weke	*Mulloides flavolineatus*	7.98	3.8
	Ta'ape	*Lutjanus kasmira*	6.77	4.0
	He'e/tako	*Octopus cyanea*	6.39	4.6
	'Ahi (yellowfin)	*Thunnus albacares*	5.95	1.1
	Palani	*Acanthurus dussumieri*	5.29	3.3
	Ulua/papio	*Caranx* spp.	5.17	7.0
	Aku	*Katsuwonus pelamis*	4.78	0.5
	Uhu	*Scarus* spp.	3.85	2.4
Maui complex	Akule/hahalalu	*Selar crumenopthalmus*	52.36	4.2
	Ulua/papio	*Caranx* spp.	5.72	10.4
	Shutome	*Xiphias gladius*	5.01	<0.1
	Uhu	*Scarus* spp.	4.74	3.5
	Opakapaka	*Pristipomoides filamentosus*	4.43	2.8
	White/green weke	*Mulloides flavolineatus*	4.07	3.7
	Uku	*Aprion virescens*	4.02	3.5
	Opelu	*Decapterus macarellus*	3.95	2.1
	He'e	*Octopus cyanea*	3.03	4.9
	'Ahi (yellowfin)	*Thunnus albacares*	2.82	1.1
Hawaii	Opelu	*Decapterus macarellus*	91.18	14.4
	'Ahi (yellowfin)	*Thunnus albacares*	41.42	5.7
	Akule/hahalalu	*Selar crumenopthalmus*	34.07	8.8
	Ono shrimp	*Heterocarpus laevigatus*	10.71	0.1
	Ono (wahoo)	*Acanthocybium solandri*	9.44	4.1
	U'u	*Myripristis* spp.	6.82	5.1
	Ta'ape	*Lutjanus kasmira*	5.61	5.0
	Ulua/papio	*Caranx* spp.	5.04	5.2
	Opakapaka	*Pristipomoides filamentosus*	4.29	3.9
	Uhu	*Scarus* spp.	4.07	2.0

[1] There are three multispecies categories (u'u, trevallies, and uhu). The species making up each of these categories are defined in Table 1.
[2] Mean annual tons = average annual weight of reported landings from 1980–90.
[3] Spp. freq. (%) = mean annual percentage of trips for 1980–90 which reported catching the species.

[18]P. Y. Kawamoto. 1973. Management investigation of the akule, or bigeye scad, *Trachurops crumenopthalmus* (Bloch). Completion rep. for NMFS under Comm. Fish. Res. Devel. Act. P.L. 88–309. Proj. H-4–R, Div. Fish and Game, Dep. Land and Natl. Res., Hawaii, 28 p.

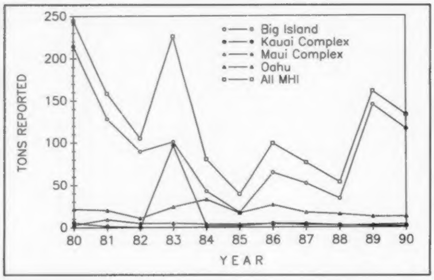

Figure 2.—Regional commercial landings of opelu in the main Hawaiian islands by island platform group.

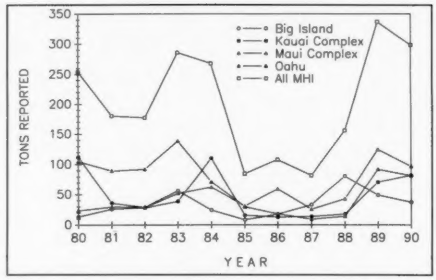

Figure 3.—Regional commercial landings of akule in the main Hawaiian islands by island platform group.

Fishing Gears and Methods

Fishing gears employed in Hawaii include various pole-and-line methods (spin casting, handlining, or trolling) from shore, pier or platform, using motorized or unmotorized boats, canoes, kayaks, or surfboards. He'e (octopus), limu (algae), and cryptic fishes such as aweoweo (glasseyes) and u'u (soldierfishes) are speared or hand-collected by diving or swimming (with or without scuba). Trolling from windsurfers, canoes, and kayaks is used to capture ulua and papio near the reef drop-offs. Huge uluas, over 40 lb, are taken in this manner. Mahimahi, ono, and billfishes can be caught by moving slightly offshore, changing to lures or live bait, and by trolling with a high speed engine. The most extensive description of Hawaii's nearshore angling methods has been compiled by Rizzuto (1983, 1987, 1990). This information is complemented by Hosaka's (1973) publication and by popular televised programs that celebrate the art of Hawaiian fishing.

Table 3 summarizes the most common inshore commercial fishing gears by island platform group. Each group has unique fisheries characteristics, but there are more similarities than differences. The most important gear around all islands is the bottom handline. Trolling (for large pelagics) is the second most important fishing method on the Kauai Complex and the Big Island; diving, spearing, and other reef methods are second in importance around Oahu and Maui. Gill netting and related methods ranked third everywhere, except on the Big Island, where surround netting (for opelu) is more important. Throw netting is more prevalent around the Maui Complex than in other areas. There is not necessarily a direct relationship between gear frequencies and the proportion of landings by gear type. In fact, the least abundant gears often show the highest catch rates. Table 4 illustrates this, showing mean catch per unit effort (CPUE) and number of trips by gear type.

The relatively low proportion of trolling trips and high proportion of trapping around Oahu are both unique to this area. Oahu is also the only is-

Table 3.—Mean proportion of inshore commercial fishing trips by gear type and geographic region.

	Relative gear abundance (% of annual trips[1])			
Fishing gear/method	Kauai complex	Oahu	Maui complex	Hawaii
Aku boat (pole and line)		0.2	<0.2	<0.1
Longline/flagline		<0.1	0.2	0.1
Drifting pelagic handline	2.5	0.7	0.5	2.8
Bottom handline	42.4	46.2	33.3	56.1
Kaka line/set line, ikashibi, palu'ahi	0.7	0.3	<0.1	1.3
Trolling	19.4	4.5	14.4	14.3
Rod and reel (light tackle)	0.1	0.2	0.2	0.5
Trap	1.9	10.7	3.0	0.8
Diving (knife, spear, hand-picked)	11.8	15.3	22.1	8.8
Seine/gillnet/hukilau net	12.5	12.1	14.9	2.7
Akule/opelu/surround/purse nets	2.1	2.7	3.5	8.8
Throw net	1.7	0.9	4.1	1.5
Lobster/crab nets	1.9	1.8	2.0	0.4
Bait net		<0.1		
Other and unspecified	3.1	4.1	1.9	1.9

[1] Tabled values are the mean annual number of trips reporting each gear type from 1980 to 1990, expressed as a percentage of the total mean annual number of trips.

Table 4.—CPUE by gear type for principal fishing gears.

	Annual mean (1980–90)		
Geartype	Trips	Landings (lb.)	CPUE (lb/trip)
Aku boat (pole and line)	36.3	10,245.6	282.2
Longline/flagline	30.3	8,648.2	285.4
Drifting pelagic handline	641.8	33,581.3	52.3
Bottom handline	8,976.8	426,581.4	47.5
Kaka line/set line, ikashibi, palu'ahi	87.2	15,992.3	183.4
Trolling	4,450.8	108,711.0	24.4
Rod and reel (light tackle)	114.5	1,141.4	10.0
Trap	371.1	57,078.4	153.8
Diving (knife, spear, handpicked)	1,154.4	91,660.6	79.4
Seine/gillnet/hukilau net	1,157.8	227,443.4	196.4
Akule/opelu/surround/purse nets	641.0	347,869.4	542.7
Throw net	681.5	7,843.4	11.5
Bait net	2.0	11.4	5.7
Lobster/crab nets	171.4	9,327.4	54.4

land supporting a major bait fishery at this time. Baitfishes (primarily nehu, or Hawaiian anchovy) were formerly harvested from Ma'alaea Bay, Maui (Nakamura, 1967) and other locations. These fisheries declined for marketing reasons during the mid-1980's (Kushima et al., 1992). Baitfishes harvested in Pearl Harbor and Kaneohe Bay are used to catch aku slightly offshore (Comitini, 1977), making Oahu the most important island for aku fishing. All aku boats presently have their home ports on Oahu.

Advances in the technology for fishing and locating fish are constantly increasing the efficiency of Hawaii's fishermen. Differences in the construction of fishing gears over the years have resulted in higher catch rates which, together with the rapidly increasing population, contribute to the potential for overfishing. For example, cotton or "linen" nets used by early Hawaiians have been replaced by monofilament nets which require less maintenance, bring in larger catches, and are less easily perceived by fish in clear water. Monofilament nets are employed along the reef faces, on the open coast and in embayments, both fixed (as a gill net) and to surround and bag fish schools (as a purse net) (DLNR, 1992). Paipai is another popular method of net fishing, whereby certain species (particularly weke) are herded into nets, either by divers or from a boat. The advent of monofilament line makes this method extremely effective, since the nets are essentially invisible in the water.

There are no trawl fisheries in Hawaii, since sharply sloping, coralline, or rocky coasts do not provide suitable substrate for trawl operations. Attempts at bottom and midwater trawling in the 1970's and 1980's were therefore abandoned. Bullpen nets are set in areas that are open and flat, facilitating the capture of large and highly mobile fishes. Sea turtles captured in bullpen nets, are easily released alive. Fish caught by surround methods can also be kept alive for long periods of time and released or harvested selectively. While many fish or turtles caught accidentally are released by conscientious fishermen, some die because people leave nets unattended or hold fish for long periods of time. This practice is particularly wasteful in Hawaii where the standard of quality for local fish consumption is high and where injured fish may not be marketable.

Other variations in fishing methods that influence catch composition include daytime vs. night fishing (and diving); diving with scuba; fishing with or without the moon; and carefully selecting seasons, tidal phases, and locations (Titcomb, 1952; Hosaka, 1973). All these tools are at the command of experienced fishermen in Hawaii, who pass on their special fishing secrets from one generation to another. Cultural heritage and family traditions, including preferences for certain species, are among the underlying factors that determine the composition of fisheries landings in Hawaii.

Geographic Trends in Catch Rates and Fisheries Exploitation

Table 5 summarizes total reported landings and provides an index of commercial harvest rates within each island platform. The index, mean annual pounds per square nautical mile of shelf, was obtained by dividing reported landings by an estimated area for each coastal shelf, based on the difference between the area of land above sea level (DBEDT, 1990) and that of a circle enclosed by the 100–fm isobath. The length of the isobath for each platform group was taken from Ralston and Polovina (1982). Landings within three miles of shore were used for the Kauai Complex, Oahu, and Hawaii. For the Maui Complex, landings and estimated shelf area within 20 miles of shore were used owing to the extensive shallows of Penguin Bank.

The index indicates a higher rate of exploitation around Oahu, as would be expected because of its large population. Oahu's landings are accomplished

Table 5.—Annual reported inshore and nearshore commercial landings and coastal harvest rates by geographic region.

Island platform group	Inshore landings[1, 2] (<3 n.mi.)	Nearshore landings[3] (3–20 n.mi.)	Total (0–20 n.mi.)	Length of 100 fm isobath[4] (n.mi.)	Estimated shelf area[5] ($n.mi.^2$) within 100 fm	Mean annual $lb./n.mi.^2$ of shelf[6]
Kauai complex	260,313 lb. 18.56 %	769,557 lb. 10.81 %	1,029,870 lb. 12.08 %	195	2,484	104.8
Oahu	372,042 lb. 26.53 %	2,737,943 lb. 38.45 %	3,109,985 lb. 36.49 %	150	1,274	292.0
Maui complex	258,738 lb. 18.45 %	1,197,168 lb. 16.81 %	1,455,906 lb. 17.08 %	390	11,080	131.4
Hawaii	511,506 lb. 36.47 %	2,416,141 lb. 33.93 %	2,927,647 lb. 34.35%	290	3,187	160.5
Total all island groups	1,402,599	7,120,809	8,523,408	1,205	18,205	144.2[7]

[1] Lb = mean annual pounds reported between 1980 and 1990 (all species).
[2] Inshore % = percent of total MHI landings reported within three nautical miles of shore.
[3] Nearshore % = percent of total MHI landings reported from 3–20 miles of shore.
[4] Length of 100-fm isobath = approximate nautical miles (from Ralston and Polvina, 1982).
[5] Estimated shelf area (ESA) = estimated square nautical miles of coastal shelf shallower than 100 fm.
[6] Mean annual $lb./n.mi.^2$ shelf = lb./ESA (landings within 20 n.mi. of the Maui complex included; only landings within 3 n.mi. for other areas).
[7] The all-islands total for "Mean annual $lb/n.mi.^2$" is based on a total of 2,599,767 lb. Landings greater than three miles from shore (nearshore) are not included for the Kaui complex, Oahu, and the Big Island.

by a large number of fishermen and catch rates per fishermen for comparable fishing effort are lower than on other islands. To compensate for this, Oahu's fishermen tend to use more fishing gear (considerably longer nets, more hooks, traps, etc.) and to fish for longer periods of time. Neighboring island residents are often astonished at the amount of effort invested by fishermen on Oahu. Reduced CPUE on Oahu may be an indication of adverse environmental impacts as well as overfishing. The Kauai and Maui groups show nearly equivalent annual landings within three miles of shore, but Maui's shallow depths extend to 3–20 miles from shore (and beyond). Once scaled to the total shallow shelf area, estimated annual catch rates (mean lb/n.mi.^{2}) around Maui are similar to those estimated for the Kauai Complex.

To evaluate catch rates around the islands, landings and CPUE (lb/trip) were summarized for the five most populated islands. Inshore catches and CPUE within 90° quadrants around each island are presented in Table 6. Trends for Kauai, Oahu, Maui, Molokai, and the Big Island indicate higher total landings and CPUE on the leeward (southwesterly) sides of all islands, in part because of increased landings of large pelagic species in this quadrant. However, there were also more trips recorded in most leeward areas. Increased pelagic productivity in leeward areas may be a function of localized upwelling and larval entrainment, driven by persistent (northeasterly) trade winds (McGary, 1955). Increased fishing activity in these areas probably results from improved sea conditions in the wind shadow of the islands, making leeward regions generally an easier place for small boats to troll and set nets. Other factors include accessibility from the shoreline and availability of launch ramps (PAC[3]). Because of their relative protection from winter storms, leeward areas are a more likely location for small boat harbors with associated launch facilities. The southwestern sector of most islands, which is also a somewhat sheltered quadrant, had the second highest number of trips.

Trends in inshore landings and CPUE from 1980 to 1990 were summarized for seven other important inshore species or groups (in addition to akule and opelu), which ranked in the top 10–20 consistently for three or more island platform groups. The groups selected were the white or green weke *Mulloides flavolineatus*; palani, *Acanthurus dussumieri*[19]; uhu, *Scarus* spp.; u'u, *Myripristis* spp.; he'e, *Octopus cyanea*; ta'ape, *Lutjanus kasmira*; and ulua/papio (jacks and trevallies, see Table 1). Statewide summaries only are provided here (Fig. 4 and 5), to show general trends in these fisheries. Regional mean CPUE by species groups are shown in Table 7. Catch rates were generally higher on Kauai and in the Maui Complex for all species.

Reef fishes are most important on the islands of the Maui Complex and on Oahu. The highest volume of uhu were seen on all sides of Oahu, as well as at Kahului, Maui; and Kailua-Kona, Hawaii. Weke, palani, u'u, and uhu are abundant in both leeward and windward landings because of the presence of well-developed reef habitats in both types of areas. Most weke were caught on Oahu's northeastern and southeastern sides, on Kauai's eastern coast, and on western Maui. Landings of green weke (Fig. 4A) have shown a gradual decline since about 1983. This is primarily attributable to decreasing CPUE, because the number of trips has remained fairly stable. The number of trips has also remained constant for uhu (Fig. 4B), whereas reported landings have varied as a function of variation in CPUE. Palani landings (Fig. 4C) have shown a decline since 1986, but this has been due to decreased fishing effort (fewer trips), while CPUE has increased or remained the same.

Table 7.—Trends in catch per unit effort (lb./trip) from 1980 to 1990 for selected species by island-platform group.

Species	Big Island	Kauai complex	Maui complex	Oahu	Mean All MHI
U'u	36.39	52.5	27.87	13.07	29.95
Ta'ape	24.41	139.41	24.18	37.45	37.22
Weke	15.70	97.75	59.19	48.88	52.14
Uhu	42.04	32.90	63.66	27.34	40.03
He'e	13.71	26.95	28.42	26.94	26.74
Palani	20.38	39.05	20.53	35.15	29.37
Ulua	29.74	38.28	31.62	21.02	28.18
Mean[1]	26.05	61.04	36.50	29.98	38.39

[1] All species.

Table 6.—Catch per unit effort (lb/trip) within 90° quadrants.

Island Group Quadrant	Mean annual lb. landed	Mean annual trips	Average CPUE (lb./trip)
Kaui			
I (Northeast quadrant)	22,156	269	82.3
II (Northwest quadrant)	30,312	231	131.3
III (Southwest quadrant)	77,149	571	135.1
IV (Southeast quadrant)	33,854	336	100.8
Oahu			
I (Northeast quadrant)	59,568	539	110.5
II (Northwest quadrant)	51,866	500	103.6
III (Southwest quadrant)	107,933	1,442	74.8
IV (Southeast quadrant)	77,263	1,073	72.0
Maui			
I (Northeast quadrant)	17,167	219	78.2
II (Northwest quadrant)	64,223	491	130.3
III (Southwest quadrant)	106,188	399	266.3
IV (Southeast quadrant)	35,020	190	184.1
Molokai			
I (Northeast quadrant)	6,297	49	127.5
II (Northwest quadrant)	4,754	55	87.1
III (Southwest quadrant)	42,912	244	175.7
IV (Southeast quadrant)	8,256	125	66.1
Hawaii (Big Island)			
I (Northeast quadrant)	33,132	573	57.8
II (Northwest quadrant)	71,775	814	88.2
III (Southwest quadrant)	284,449	2,025	140.5
IV (Southeast quadrant)	77,878	965	80.7

[19]It should be noted that two other surgeonfishes, known locally as "pualu" (*Acanthurus xanthopterus* and *A. mata*) are difficult to distinguish from the palani. Although separate records are kept when these species are reported separately, some pualu may be included in palani landings if they are not distinguished by fishermen.

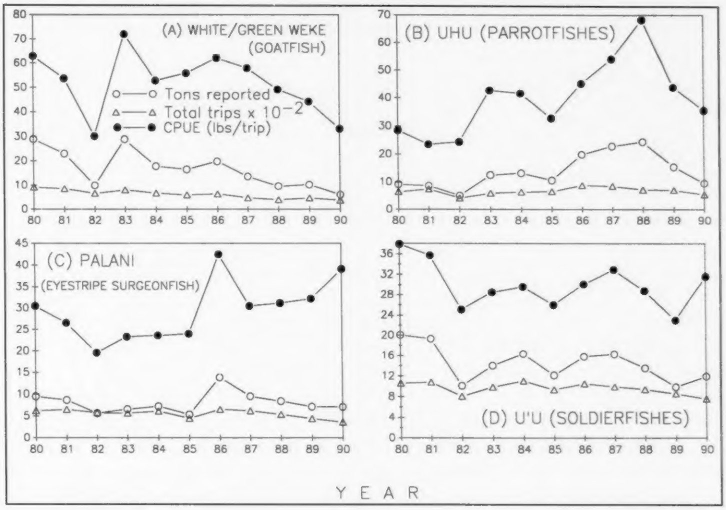

Figure 4.—Reported inshore commercial landings of selected species in the main Hawaiian islands.

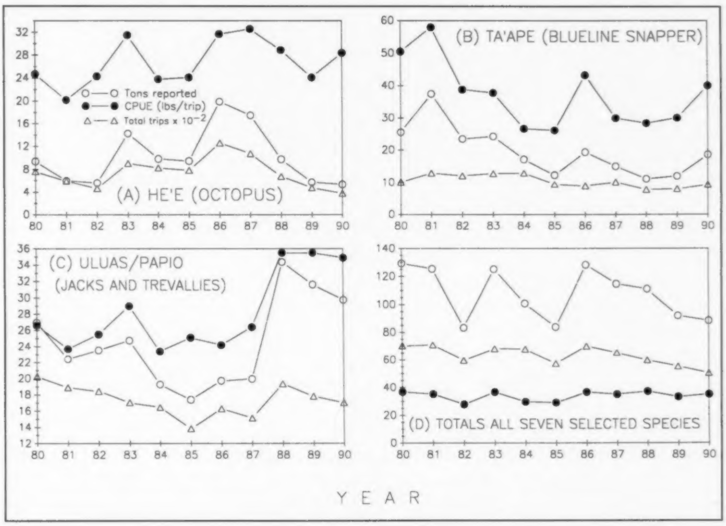

Figure 5.—Reported inshore commercial landings of selected species in the main Hawaiian islands.

The entire leeward coast of Oahu, windward and leeward Maui, and the Kailua-Kona Coast, have shown the highest landings of palani. U'u landings (Fig. 4D) have fluctuated over the years because of varying effort and CPUE.

He'e (octopus) is another reef species for which landings have fluctuated as a function of cyclical changes in the number of trips and the magnitude of CPUE. Figure 5A shows that the decline in reported landings since 1986 is due to fewer reported trips. However, this species is caught in large numbers by noncommercial fishermen (Everson[15]; Hamm and Lum[14]), and commercial trends do not tell the whole story. Kahului (Maui) registered the highest he'e landings in the state, followed by Kaneohe Bay (Oahu). Both

are windward locations with a fairly wide shelf and reef area.

The introduced ta'ape are abundant everywhere, much to the dismay of residents who prefer native fishes (Kushima[20]). Reported landings (Fig. 5B) have been largely determined by fluctuations in CPUE. Ta'ape are caught in large numbers by surroundnet fishermen, who normally target akule. Their landings are limited primarily by the local market, which becomes flooded when too many fish are caught. Uluas were also important on all islands; however, noncommercial landings are an important component of this multi-species fishery. Ulua landings at Penguin Bank are roughly three times the volume recorded elsewhere, but the shelf area is also considerably larger. Figure 5C shows trends in ulua landings for all islands. The regional makeup of the catch by species indicates that the most diverse fisheries are found at Oahu and in the Maui Complex, followed by the Big Island, and finally Kauai. However, an in-depth evaluation of this group by species is limited by the tendency of fishermen to lump the fish together in their catch reports as simply "ulua" or "papio."

Total reported landings, trips, and CPUE for all seven species above are shown in Figure 5D, where an overall decline since 1986 is seen. While CPUE fluctuates or remains equivalent over the same period, the number of trips reported is steadily decreasing. The reason for this is unclear, but would seem not to indicate any cause for concern, since fishermen would appear to be voluntarily reducing their effort or merely switching to more lucrative offshore fisheries. However, it must be kept in mind at all times that reported commercial landings do not represent all inshore catch and effort. Another point worth noting is that the DAR began entering information on "no-catch" trips in the database in 1989. This information has not been included in the present summaries, but in the next decade its existence may allow a more accurate assessment of changes in CPUE.

[20]J. N. Kushima. 1989. Ta'ape market development project. Div. Aquatic Res., Dep. Land and Natl. Res., Hawaii, 29 p.

Additional Considerations

Aquarium Landings

Although the foregoing summaries provide a brief insight into the makeup of Hawaii's nearshore commercial fisheries, there is much room for further consideration. No attempt was made here to summarize catches by aquarium collectors. Van Poollen and Obara (1984) profiled early economic characteristics of the marine aquarium industry in Hawaii. Aquarium landings are reported to the DAR and have been summarized by Miyasaka[21]. There were 231 aquarium collectors with permits in the State in 1988 (DLNR, 1988), of which 42% were commercial collectors. These fishermen reported catching 249,625 small fishes and invertebrates comprising about 215 species during 1988, of which 53% were collected from inshore areas on the Big Island's Kona Coast. The commercial value of these landings was estimated at $411,425 (all islands).

This is a rapidly expanding industry, responsible for an increasing proportion of the market value of commercial landings. A recent analysis provided by the DAR to the Kaneohe Bay Master Planning Task Force (OSP[4]) showed that while the total weight of commercial landings in Kaneohe Bay has declined over the last 12 years, aquarium collectors have increased the value of these landings, primarily through the sale of reef invertebrates. The desire to increase profits, however, cannot overshadow the need for resource conservation. Juvenile fishes are collected from inshore reefs, particularly along the leeward coast of the Big Island. Recent regulatory measures (DAR[22]) are aimed at moderating the impacts of these fisheries by controlling them in certain locations. Although the importance of aquarium fisheries cannot be overlooked, this topic merits a separate review.

[21]A. Miyasaka. 1991. Hawaii's aquarium fish industry: A business profile. Div. Aquatic Res., Dep. Land and Natl. Res., Hawaii, 15 p.

[22]Div. Aquatic Resources, State of Hawaii. 1992. Regulations for the new Kona FMA. In press.

Markets

Local marketing opportunities for Hawaiian fishermen are limited, as might be expected in this isolated region. Each island has its own small markets, including spontaneous roadside ventures which spring up and disappear overnight. There are two principal auction houses, one on the island of Oahu and one on the Big Island. It is estimated that these two auctions are responsible for from 50 to 60% of fish sold commercially in the state. However, these markets cater to offshore fisheries and primarily service longline and bottom handline fishermen. Reef fishes are increasingly being sold directly to individual vendors.

A recent increase in the number of ciguatera poisoning incidents reported to the State Department of Health has resulted in alarm regarding the consumption of reef fish captured locally, dramatically reducing the marketability of some inshore species and shifting fishing effort to areas where there have been no reported incidents. Although the danger of ciguatera may be largely exaggerated, vendors prefer to err on the side of caution. Fish are also exported without passing through the local markets. The subject of markets and landings value will be treated in depth by another contributor to this volume and is also beyond the scope of the present review.

Nonconsumptive Uses of Marine Fisheries Resources

Other important considerations in Hawaii include a variety of commercial nonconsumptive uses of inshore fisheries resources. Tourists enjoy activities designed to allow observation of reef fishes in their natural environment. This may be done from a boat or submersible, or by actually entering the water using a mask and snorkel. The lucrative industry associated with the latter type of viewing activity may involve bringing large groups of relatively inexperienced swimmers into contact with shallow inshore reefs, causing extensive trampling of fragile

corals and destruction of the reef habitat. Both types of fish-viewing commercial tours generally involve some means of feeding the fish in order to concentrate them in an area where they can be seen. The result can be localized increases in abundance of the more aggressive and omnivorous species.

One of the present challenges to fisheries management in Hawaii is to preserve a healthy and abundant reef ecosystem that tourists can enjoy and at the same time allow fishing to take place at a reasonable level. The use of motorized recreational vehicles, such as jetskis and water skis, drives fish from the immediate area. Fishermen are responding to increased daytime commercial recreation by switching to nighttime fishing activity. Presumably fish viewing, ocean recreation, and fishing can coexist peacefully. Modern management measures must include setting allowable levels for ocean recreation, in addition to limits to fishing.

Fisheries Management

Status of Biological Knowledge of Stocks

Despite the importance and multiuse orientation of inshore resources, surprisingly little is known about the abundance and status of fisheries in Hawaii. Even generalized summaries of trends, such as are reported here, have rarely been attempted for inshore species. An exhaustive study would have to evaluate trends in these fish communities altogether, as an ecosystem. Changes introduced by humans in inshore habitat over the years may exert extremely important influences on fish abundance.

A DAR[10] report provided one of the most comprehensive summaries to date of the complex cultural, traditional, ecological, and jurisdictional issues involved in the management of Hawaii's inshore fisheries. In a survey fishermen described gear conflicts and reduced catches. Both fishermen and scientists expressed concern regarding whether the decline in nearshore fish populations might be due to increased fishing pressure and habitat alteration. The status of fishery resources was, and continues to be, viewed as a "barometer for the condition of our aquatic ecosystem." An examination of available (commercial) data at that time showed that fluctuating inshore fisheries landings were neither increasing nor declining significantly despite increased fishing effort. While CPUE was declining, it appeared that an equivalent amount of landings was being shared among an increasing number of fishermen. Various management scenarios were envisioned which would optimize CPUE for different sectors of the fishery and protect habitats critical to fish populations from the impacts of coastal development. The need for a careful evaluation of multi-species and multi-gear fisheries was stressed, as was the need for more complete and reliable fisheries data.

Shomura[23] summarized data from the State's commercial landings database, documenting an apparent decline in nearshore and both neritic and pelagic catches since the early 1900's. As in the DAR report, the data summarized by Shomura was in the form of statewide totals for many species and a wide range of geographic areas. Furthermore, no index of fishing effort was provided, making it difficult to interpret apparent trends. Shomura indicated that while deep slope and offshore pelagic landings had increased significantly, inshore and coastal landings were declining. The increase in offshore landings could be attributed to the effect of increased market demands on fishing effort. Decreasing reef fish landings might conversely be attributed in part to low relative demand for certain reef fishes, because of their distinctive flavor and odor of marine algae. Although local residents and native Hawaiians enjoy these distinctive tastes, tourists and foreign markets do not appreciate them.

The present summary, like those before it, encompasses a great deal of complexity which merits a more in-depth examination. As such, this review is considered to be a contribution to the understanding of trends in Hawaiian fisheries, indicating that assessment and management should be examined on a regional basis. While total landings for the state may have decreased since the early 1900's, regional evaluations show a wide range of variation. Some inshore fisheries show short-term improvements, although increased reporting may contribute to this apparent trend. The most disturbing trend is towards steadily increasing fishing effort in inshore ecosystems that are already heavily exploited. Most fisheries managers agree that fishing pressure should be reduced or limited in some areas in Hawaii; but answers to questions such as where, how much, and in what manner are still being sought.

Ongoing Research

A project presently in progress, the Main Hawaiian Islands Marine Resources Investigation (MHI-MRI), is beginning to consolidate information on inshore fisheries and evaluate abundance, CPUE, and life history data for key species and areas. This project of the DAR is being conducted in collaboration with other fisheries management and marine research agencies statewide. Participants include the University of Hawaii Sea Grant College Program, Marine Option Program, Hawaii Institute of Marine Biology, and Hawaii Institute of Geophysics; the NMFS Southwest Fisheries Science Center, Honolulu Lab; the Oceanic Institute; the Western Pacific Regional Fisheries Management Council; and the USFWS Hawaii Cooperative Fisheries Research Unit. The project also cooperates with the International Center for Living Aquatic Resources Management (ICLARM) in the context of FISHBASE, a worldwide computerized database of biological information on fishes (Pauly and Froese, 1991), to obtain jointly a complete coverage of the fishes of the Central Pacific.

MHI-MRI will reevaluate the management of inshore fisheries throughout the MHI, and produce long-term recommendations to improve resource

[23]R. Shomura. 1987. Hawaii's marine fishery resources: Yesterday (1900) and today (1986). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-87-21, 14 p.

abundance and ensure sustainable fisheries. Research in progress seeks to define the principal causes of the declining abundance of some inshore species and to identify mitigative measures to offset negative impacts as needed. Overfishing, increased erosion and sedimentation, and both alterations and pollution of inshore habitats are among factors under investigation. Early indications are that limitation of fishing pressure, localized stock enhancement, and protection of inshore nursery areas from further human impacts could all contribute to recovery of inshore fish populations in Hawaii.

Regulatory Measures

Existing regulatory measures for Hawaiian inshore fisheries include bag limits, seasonal closures, and minimum size restrictions for capture and sale. Gear restrictions inside harbors allow pole-and-line fishing using only one pole with two hooks per fisherman. Crab netting in these areas must be limited to ten (small circular) nets per fisherman. Fishing regulations are summarized for the public in a brochure, updated annually by the DAR (DAR[24]). In addition to these regulations, there are specific gear restrictions in areas designated as Fishery Management Areas (FMA's) and MLCD's.

FMA's are established in areas where fishing or resource use competition is a problem and generally involve restriction of fishing gears or uses. Examples include the Waikiki-Diamond Head Shoreline FMA (Oahu) and Hilo Harbor FMA (Hawaii), where net fishing is restricted. The Waikiki-Diamond Head FMA rules rotate gear restrictions annually. Pole-and-line, thrownet or handnet fishing, and daytime spearing are allowed during even numbered years. No fishing is allowed in odd numbered years. Hilo Harbor FMA is regulated differently, tailored to the needs of local fishermen. In addition to bag limits, no gill, surround, or cross netting is allowed at any time within the Hilo breakwall, but all types of fishing are permitted year-round outside this area. Measures that regulate fishing pressure, while maintaining fishing opportunities for a variety of users, are more widely accepted in local communities. The benefits of these measures are demonstrated by an almost immediate increase in resource abundance, as indicated by increases in estimated biomass, in average and maximum size of fish captured, and in CPUE (Yamamoto[16]; Kahiapo and Smith[5]).

Molokini Crater, southwest of Maui, is a State-regulated MLCD. Only trolling is presently allowed in this partially submerged crater, which is a popular tour site for divers; but measures are being considered to restrict trolling as well. Other MLCD's and FMA's dot the coasts of the MHI (DAR[25]; Oishi[2]). Regulations are site specific, but generally, where fishing is allowed, it is restricted to pole-and-line, hand methods, and throw netting.

As seen under fishing methods, gears such as longlines, gill nets and surround nets are responsible for a large volume of landings in relation to the number of trips and fishermen. This is fine as long as the resource is not over harvested. These fleets are small and in some cases, such as for longline fishing, limited entry schemes are being developed to conserve resources for future generations. Other fisheries, such as surround netting, are presently limited by social constraints worked out through "gentlemen's agreements" between fishermen. As fishing pressure increases because of immigration and population growth, the need to formalize these agreements becomes increasingly important.

Ancient Hawaiians practiced seasonal closure of certain areas to fishing. Traditional systems provided for seasonal, species, and area-specific harvesting. The practices of sharing the catch, leaving certain species to royalty, and never taking more than was needed contributed to the balance between fishing and conservation in early times (Titcomb, 1952; Johannes, 1978). The loss of the traditional Hawaiian fishery management system and the failure to replace it with something comparable when Hawaii became part of the United States (Jordan and Evermann, 1905; Titcomb, 1952; Johannes, 1978; DAR[10]; Smith and Pai, 1992) are impacts from which nearshore living resources may take a long time to recover. A "kapuku" plan proposed in the late 1970's (HMR[26]) was one of the first attempts to restore a system of rotating area closures; however, agreement could not be reached on the specific areas to be closed. Present regulations, with rotating FMA's and MLCD's parallel this type of system on a small scale, but it is apparent that more protection of inshore resources is needed.

Because the jurisdiction of fisheries regulatory agencies in Hawaii is determined by geographic boundaries which do not coincide with the boundaries of migratory organisms that make up its fisheries, collaboration and cooperation between these agencies is critical to successful management. Environmental protection is another increasing concern that has demonstrated value to the conservation of inshore fisheries resources. Collaboration is being developed, and economic, scientific, and enforcement resources pooled, in order to manage the resources more effectively. It is clear from the long hours dedicated by the public to meetings designed to guide management efforts that residents are concerned about maintaining their rich and diverse natural heritage. The improved management of inshore fisheries and fishery habitats is an issue which must be resolved before the end of the present decade, and Hawaii's residents and resource managers are rising to meet the challenge.

Acknowledgments

Special thanks are due to a number of local fisheries biologists for their

[24]Div. Aquatic Resources, State of Hawaii. 1991. Hawaii fishing regulations. Div. Aquatic Res., Dep. Land and Natl. Res. brochure, 43 p.

[25]Div. Aquatic Resources, State of Hawaii. 1991. Marine life conservation districts. Div. Aquatic Res., Dep. Land and Natl. Res. brochure, 30 p.

[26]Hawaii Marine Research, Inc. 1977. Plan of action for the implementation of the Kapuku Plan of Management. Prepared for Hawaii Dep. Land and Natl. Res. by Hawaii Marine Res., 47–267 Kokokahi Place, Kaneohe, HI 96744, 190 p.

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Precious Coral Fisheries of Hawaii and the U.S. Pacific Islands

RICHARD W. GRIGG

Introduction

Precious corals have been used by humans for the fabrication of coral jewelry since antiquity (Grigg, 1989). Along with amber, precious coral may have also been used as a source of currency for trade by paleolithic man (Tescione, 1968). As a renewable resource in the sea, precious corals are thought to be the slowest growing organisms of any known fishery past or present. Pink and red coral fisheries exist in the Mediterranean Sea and the Pacific Ocean. Black corals are distributed world-wide and small fisheries for black coral exist in all oceans. Hence, precious corals represent a unique and interesting case history of a fishery which is very old and quite widespread and one which renews itself very slowly. In this paper, these aspects of the fishery are considered but only as they relate to the modern history and management of precious coral fisheries in Hawaii and the Western Pacific during the past 35 years. Over this period in this area, two different precious coral fisheries have been developed; one in relatively shallow water between 30–100 m for several species of black coral, and the other, for pink, gold, and bamboo corals at depths of 400–1500 m. A brief history of both fisheries is presented including a description of their ecology and management of target species. Future research needs for both fisheries are described and future prospects of the precious coral industry are considered.

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ABSTRACT — The precious coral fishery in Hawaii and the Western Pacific consists of one industry but two distinct and separate fisheries. The first is the harvest of black coral by scuba divers from depths of 30–100 m. The second is a fishery for pink and gold coral at depths between 400 and 1500 m and employs either a human-operated submersible that permits selective harvest or tangle net dredges which are nonselective. The modern history of these fisheries date from 1958 until the present. In this paper the ecology, life history, and management of the dominant species that make up these fisheries are reviewed. Research needs of the fisheries and the economic and future prospects of the precious coral industry are also described. At the present, the precious coral jewelry industry in Hawaii (all species) is valued at about $25 million at the retail level.

Taxonomy

Briefly, all species of precious coral in the Western Pacific belong to one of three Orders within the Class Anthozoa, Phylum Coelenterata. The pink and bamboo corals, *Corallium* spp. and *Lepidisis olapa*, are in the Order Gorgonacea. The Hawaiian gold coral, *Gerardia* sp., is in the Order Zoanthidae and the black corals, *Antipathes dichotoma, A. grandis, A. ulex,* and *Cirrhipathes anguina*, are all in the Order Antipathidae. Gorgonians are octocorals while the Hawaiian gold and black corals are hexocorals.

History of the Precious Coral Fishery in Hawaii and the Western Pacific

Commercial beds of black coral were discovered in Hawaii in 1958 by Jack Ackerman and Larry Windley (Stewart, 1962a; Grigg, 1965). This discovery was located 4.8 km due west of Lahaina, Maui, at a depth of 30–75 m along a drop-off known as "stone wall" on the Lahaina Roads Reef. What Ackerman and Windley had discovered were populations of two species of exceedingly large black corals, *Antipathes dichotoma* and *Antipathes grandis* (Fig. 1). Subsequent research has shown that 12 additional species exist in Hawaiian waters but most of these occur at depths below 100 m, and none are large enough or are of sufficient quality to be of commerical value for coral jewelry (Grigg and Opresko, 1977).

The discovery of black coral in Hawaii in 1958 led to the establishment of a small cottage industry that produced curios and black coral jewelry in Lahaina, Maui (Stewart, 1962b). In 1960, John Stewart and Jack Ackerman started a company known as Maui Divers. Over the next ten years, Maui Divers grew steadily under the direction of Clifford Slater, and was joined by about a dozen other small companies. By 1969 the industry collectively was producing about $2 million gross retail sales; part of these sales included imports of pink coral jewelry from Taiwan and Japan.

In 1965, Japanese coral fishermen discovered a huge bed of commercial pink coral at about 400-m depth on the Milwaukee Banks in the Emperor Seamount Chain north of Midway Island near the northwesternmost end of the Hawaiian Archipelago. In terms of significance to the United States, only about 10% of the entire area (the so-called Midway Grounds) exist within the U.S. economic zone (EEZ). Nevertheless, as a result of this discovery, interest in precious coral resources dramatically increased in Hawaii. This stimulated new exploration in the high

Figure 1.—Jack Ackerman and Larry Windley display a large colony of *Antipathes dichotoma* collected from a depth of 65 m off Lahaina, Maui. The colony is dead and encrusted with numerous sponges and other invertebrates. Even so, the skeleton is still of commercial quality for the manufacture of coral jewelry.

Hawaiian Islands and in 1966, Vernon Brock and Ted Chamberlain of the University of Hawaii discovered a small bed of pink coral *Corallium secundum*, near 400 m depth off Makapuu, Oahu (Fig. 2). In the following three years, a small group of fishermen dredged the Makapuu Bed for pink coral on a small scale using tangle nets (Fig. 3).

In 1970 a long-term research program on precious corals began at the University of Hawaii and this led to the development of a selective harvesting system utilizing a manned submersible (Grigg et al., 1973; Figure 4). In 1973, Maui Divers of Hawaii incorporated this system and began a commerical operation of selective harvest for pink, gold, and bamboo coral which lasted until 1978. The gold coral (*Gerardia* sp.) and bamboo coral (*Lepidisis olapa*) (Muzik, 1978) coexist within the same depth zone and habitat with *Corallium secundum*. The Maui Divers operation lasted 6 years but was discontinued in 1978 because of high operating costs. The annual harvest of pink and gold coral from the Makapuu Bed during this period is given in Table 1. Since this time, the industry in Hawaii has relied on stockpiles of gold coral and exports of pink and red corals (*Corallium* spp.) mostly from Taiwan and Japan. The only other attempt to harvest pink corals domestically within the Western Pacific EEZ was in 1988, when crew members of the vessel *Kilauea* used nonselective tangle nets at Hancock Seamount. Their catch was only 450 kg of *Corallium secundum* and most of the colonies harvested were dead and of low quality.

Because Hawaii's precious coral industry continues to be dependent on sources of raw material outside the US EEZ, it is important to analyze trends in the supply of *Corallium* spp. Pacific-wide. From the time of the major discovery of *Corallium secundum* on the Milwaukee Banks in 1965 to the present, the annual supply of both pink and red corals has been extremely erratic. The harvest of shallow water *Corallium* by Japanese and Taiwanese coral fishermen first peaked in 1969 when production Pacific-wide reached 150 metric tons. Following this boom year, production fell precipitously and remained low for the next five years

Table 1.—Annual harvest of pink and gold coral from the Makapuu Bed (kg).

Year	Gear	*Corallium secundum*	*Gerardia* sp.
1966–69	Dredge	1800	0
1970–72	No harvest	0	0
1973	Submersible	538	0
1974	Submersible	2209	734
1975	Submersible	1385	621
1976	Submersible	400	363
1977	Submersible	1421	329
1978 (Jan–June)	Submersible	474	50
1979–92	no harvest	0	0

Figure 2.—*Corallium secundum* (center) at a depth of 390 m in the Makapuu coral bed. The substratum consists of a hard fossilized limestone. It is swept by strong bottom currents which prevent the buildup of sediments. The measuring rod is marked at 10 cm intervals.

Figure 3.—A = Coral tangle dredges consisting of stones with attached netting.

(Grigg, 1984). Accurate statistics for these years are not available. Then in 1978, a deep-water undescribed species of *Corallium* (sp. nov.) was discovered by a Japanese fishermen at depths between 900 and 1500 m on the Emperor Seamounts. While the color of this species is spotty (sometimes called Scotch), varing between pink and white, it was extremely abundant, and like the 1965 discovery, it produced a "coral rush." In the peak year of 1981, over 100 coral boats from Japan and Taiwan fished the Midway Grounds and production neared almost 300 metric tons (t) Pacific-wide (Table 2). Unfortunately, this intensive fishing effort led to a gradual depletion of the resource, illustrating the well established pattern for all precious coral fisheries: exploration, discovery, exploitation, and depletion (Grigg, 1989).

By 1991, production Pacific-wide stood at an all time low of 2,930 kg (Table 2) and prices of raw material were at unprecedented highs. According to the American Institute in Taiwan, coral production in Taiwan fell to

Table 2.—Total foreign yield (kg) of precious coral (*Corallium* spp.) in the Pacific during the years 1979–91.

	Japan				
Year	Midway grounds	Western Pacific	Submersible	Taiwan (All areas combined)	Total
1979	76,988	14,516	0	123,000	214,504[1]
1980	74,228	10,227	0	154,000	238,455[1]
1981	30,484	5,381	775	254,000	290,640[2]
1982	52,166	3,000	551	69,200	123,917[2]
1983	51,087	2,947	306	109,000[3]	163,493[2]
1984	33,164	3,315	634	157,000[3]	194,113[2]
1985	9,322	2,366	816	214,000[3]	226,504[2]
1986	1,650	1,268	1,261	141,000[3]	146,179[2]
1987	585	1,986	425	106,000[3]	108,977[2]
1988	217	1,605	1,082	50,000[5]	52,094[2]
1989	1,961	1,057	938	5,400[6]	9,156
1990	0	(2,172[4])		1,000[6]	3,172
1991	0	(1,390[4])		~1,000[6]	~2,930

[1] Grigg, 1984.
[2] All Japan Coral Fishing Association.
[3] Coordination Council for North American Affairs, Taipei, Taiwan, D. K. P. Liu.
[4] D. M. Ancona, Embassy of the United States, Tokyo, Japan. Western Pacific and submersible catch combined.
[5] Taiwan Fisheries Bureau, Sing-Hwa Hu. Personal commun. 1989. Taipei.
[6] Personal Communication, Vanila Lin, Taipei, Taiwan. 1990.
[7] American Institute in Taiwan, M. J. Matthews. Personal commun. 1992 Taipei.

Figure 3.—B = Japanese coral fishing boat showing line haulers, tangle net dredges, and rollers on side of vessel.

1 t in 1990 but exports drawn from previous year stockpiles were 63 t of coral products. As stockpiles of the resource are gradually reduced worldwide, new production will depend on the discovery of new precious coral beds. This boom and bust cycle of harvest and supply dramatically illustrates the need for management of the fishery. Management has been hampered by the multinational character of the fishery and because many precious coral beds exist in international waters.

In contrast to the pink and red coral fishery in the Pacific, the black coral fishery in Hawaii is relatively stable. While demand has fluctuated considerably over the years since its discovery in 1958, the supply of black coral has never failed to meet demand. In the early years of the industry during the 1960's and early 70's, as much as 10,000 kg were harvested annually from the black coral beds off Maui and Kauai. During the late 70's and early 80's the demand for black coral was greatly reduced, being replaced by a higher consumer interest in pink and gold coral. However, since about 1986, demand for black coral has been steadily increasing. Consumption by one company, Maui Divers of Hawaii, Ltd., illustrates this trend (Table 3).

Table 3.—Consumption of Hawaiian black coral by Maui Divers of Hawaii, Ltd., 1982–92.

Year	Weight (all species combined), kg
1982	78
1983	70
1984	257
1985	278
1986	463
1987	934
1988	432
1989	824
1990	1295
1991	1740
1992 (Jan–July)	1238

Production by Maui Divers of Hawaii accounts for more than 50% of all locally produced black coral jewelry in the State of Hawaii. Today, considerably less black coral is used for fabrication than during the 60's and 70's because the jewelry items produced are smaller and of higher quality and because modern cutting procedures are much more efficient than in the past. In November of 1987, black coral was named the State "Gem" and this has increased consumer interest considerably.

Over the years, the stability of the industry has been aided by the availability of inexpensive black coral from the Philippines and Tonga (Harper, 1988). These sources have filled the demand for low quality but high volume jewelry products. Also black coral resources in Hawaii have been well managed by local fishermen who voluntarily do not harvest colonies below

Figure 4.—As the Maui Divers *Star II* submersible approaches the surface, a subtender using scuba collects gold coral, *Gerardia* sp., from the basket.

48 inches (1.2 m) in height. This size limit has been adopted by the Western Pacific Regional Fisheries Management Council and has been recommended to the State of Hawaii and is based on the growth rate and reproductive pattern of *Antipathes dichotoma* and calculations of maximum sustained yield (Grigg, 1976).

Overall, the precious coral industry in Hawaii has steadily grown over the past 34 years since its inception. At the retail level today, the precious coral industry is valued at about $25 million and consists of about 100 retailers.

A small but stable black coral fishery in Hawaii continues to thrive while the fishery Pacific-wide for *Corallium* spp. has drastically declined owing to depletion of the resource. Present demand for *Corallium* is being met largely by the utilization of stockpiles. The future of the *Corallium* fishery will depend on the discovery of new beds of commercial grade species of pink and red coral.

Ecology of precious corals

The ecology and patterns of life history of various species of precious corals have been reviewed by Grigg (1974, 1976, 1984, 1989). In general, most species of precious corals are slow growing, have low rates of recruitment and mortality, and consequently are relatively long lived. The oldest colonies of *Corallium secundum* in the Makapuu Bed off Oahu probably reach an age of 75 years, and the largest colonies of *Antipathes dichotoma* and *A. grandis* may even be older. Populations of both *Corallium secundum* and both black coral species appear to be recruitment limited (Grigg, 1988). In favorable environments for *Corallium secundum* and *A. dichotoma* in Hawaii, populations are relatively stable suggesting that recruitment and mortality are approximately in steady state. However, in suboptimal environments, the age frequency distributions of both species are very uneven or truncated probably owing to episodic mortality events (personal observation).

Mortality is most often the result of smothering by sediments and by bioerosion of the substrata which leads to toppling of colonies. Fragmentation and reattachment (asexual reproduction) appears to rarely occur. Most species of precious coral are uni-sexual or dioecious, i.e. the sexes are separate. The age of reproductive maturity of *Corallium secundum* and *A. dichotoma* is similar, occurring about age 12–13 which is about one-sixth the longevity of the oldest colonies. Fertilization of Hawaiian precious corals appears to take place externally within the water column. The duration of the larval stage is unknown for most species of precious coral, but studies of one species, *Corallium rubrum*, in the Mediterranean Sea suggest that larvae of this species remain competent for several weeks (Vighi, 1970). In general, settlement is most successful on clean swept surfaces exposed to strong bottom currents. The larvae of both species of *Antipathes* in Hawaii are known to be negatively phototactic which explains why they are not found at shallow depths (< 30 m) and are most abundant beneath overhangs and on other dimly lit surfaces (Grigg, 1965).

The ecological requirements of all species of precious coral in the western Pacific can be briefly summarized as follows. All species require a firm (rocky) substratum free of sediment and most thrive in areas swept by moderate to strong currents. All species lack symbiotic algae in their tissues (ahermatypic) and most are found in deep water below the euphotic zone (Table 4). All species are filter feeders and many are fan-shaped, a growth form which maximizes contact of feeding surfaces with particles or microplankton entrained in the water column. Light and temperature appear to influence larvae more than adults. The lower depth limit of *A. dichotoma* and *A. grandis* coincides with the top of the thermocline in the high Hawaiian islands. Larvae may avoid settling deeper where lower temperature may prevent reproduction (Grigg, 1977, 1984). Species of *Corallium* exist below the euphotic zone at depths between 350 and 1,500 m where temperature varies between 14° and 3°C.

Resource management

The life history attributes of all species of precious corals in the western Pacific make these living resources highly vulnerable to over-exploitation in unmanaged fisheries. This is because many year classes are exposed to harvesting at the same time. Virtually decades of accumulated standing stock can be collected during short intensive periods of fishing. Indeed, the historical pattern of the fishery worldwide is one of discovery, exploitation and depletion.

Historically, species of *Corallium* have been harvested non-selectively using various types of dredges. In the Meditteranean Sea a heavy wooden cross outfitted with tangle netting (The Cross of Saint Andrew) is dragged across the bottom where corals are broken and entangled in the mesh. Japanese and Taiwanese fishermen also use tangle gear although theirs is simpler in design, consisting of either stones or iron bars with attached netting (Fig. 3). Since the inception of SCUBA, shallow water colonies in the Mediterranean Sea (up to 110 m in depth) have been harvested selectively by divers. In Hawaii the black coral fishery also employs SCUBA divers who selectively harvest colonies with axes, hammers, and saws (Fig. 4). The first selective harvest of *Corallium* in which a submersible was used by Maui Divers of Hawaii in 1973. This was accomplished with the use of a sophisticated cutter, claw, and basket assembly that was attached to the submersible (Fig. 5, Grigg et al., 1973). Since 1983 an unmanned submersible (robot) has been used in Japan to harvest selective species of precious coral in traditional seas (Table 2).

Precious coral resources in Hawaii and the Western Pacific fall under the

Table 4.—Depth zonation of all species of precious coral in the western Pacific.

Species and common name	Depth range (m)
Corallium secundum, Angle skin coral	350 –475
Corallium sp. nov., Midway deepsea coral	1000–1500
Gerardia sp., Hawaiian gold coral	300–400
Lepidisis olapa, bamboo coral	350–400
Antipathes dichotoma, black coral	30–100
Antipathes grandis, pine black coral	45–100
Antipathes ulex, fern black coral	40–100
Antipathes anguina, wire black coral	20–60

Figure 5.—A black coral diver in Hawaii approaches a small colony of *Antipathes dichotoma* at a depth of 50 m off Lahaina, Maui.

management authority of the State of Hawaii and the U.S. Federal government. The State has clear jurisdiction over resources out to three miles but also claims authority over inter-island waters. Hence the State has declared jurisdiction over the Makapuu Coral Bed situated 9 km (6 miles) off Makapuu in the channel between Oahu and Molokai. Federal jurisdiction extends from 3 miles outside the State of Hawaii, Guam, and American Samoa to 200 miles, and from the shoreline of all U.S. possessions in the Western Pacific (Johnson Atoll, Kingman Reef, and Palmyra, Wake, Jarvis, Howland and Baker islands) to 200 miles. This area is defined as the U.S. Exclusive Economic Zone (EEZ).

Presently black corals in Hawaiian waters are managed by the State of Hawaii. Fishermen are required to have commercial fishing licenses and report their catch monthly to the Hawaii Division of Aquatic Resources. A state regulation has been drafted which sets a minimum size of 48 inches in colony height and 3/4" in basal diameter for the harvest of *A. dichotoma* and *A. grandis*. At the present time, black coral divers in Hawaii comply voluntarily with this draft regulation.

Precious coral resources within the U.S. EEZ (Fig. 6) are managed by the Western Pacific Regional Fishery Management Council (WESTPAC), under a Fishery Management Plan (FMP) for precious coral (Dep. of Commerce, 1980). The FMP, finalized in September 1983, allows for domestic and foreign fishing by regular or experimental permits and requires logbooks of the permittees. Specific regulations contained in the FMP are as follows:

The FMP and regulations outline and classify the known beds of precious corals within the Western Pacific Region, and designate harvesting method and the amount of corals that can be harvested. There are four bed classifications: 1) Established Beds, 2) Conditional Beds, 3) Refugia Beds, and 4) Exploratory Permit Areas. Established beds are ones with a history of harvest, and optimum yields have been established on the basis of biological stock assessment techniques, and selective harvesting gear (submersibles or remote control harvester vehicles) is required. Makapu'u is the only designated Established Bed. Conditional beds are ones for which yields have been estimated on the basis of bed size relative to established beds with the assumption that ecological conditions at established beds are representative of conditions at all other beds. Four beds are designated as conditional beds: Kea-hole Point, Kaena Point, Brooks Banks, and 180 Fathom Bank. Nonselective harvesting is permitted only in the two conditional beds in the Northwest Hawaiian Islands (Brooks and the 180 Fathom Banks). A refugia bed is one set aside to serve as a baseline study area and possibly reproductive reserve. No harvesting of any kind is permitted in Refugia. Presently, the WESTPAC bed, between Nihoa and Necker Islands, is the only designated Refugia. Exploratory permit areas are unexplored portions of the EEZ in which coral beds are almost certain to exist, but no beds have yet been lo-

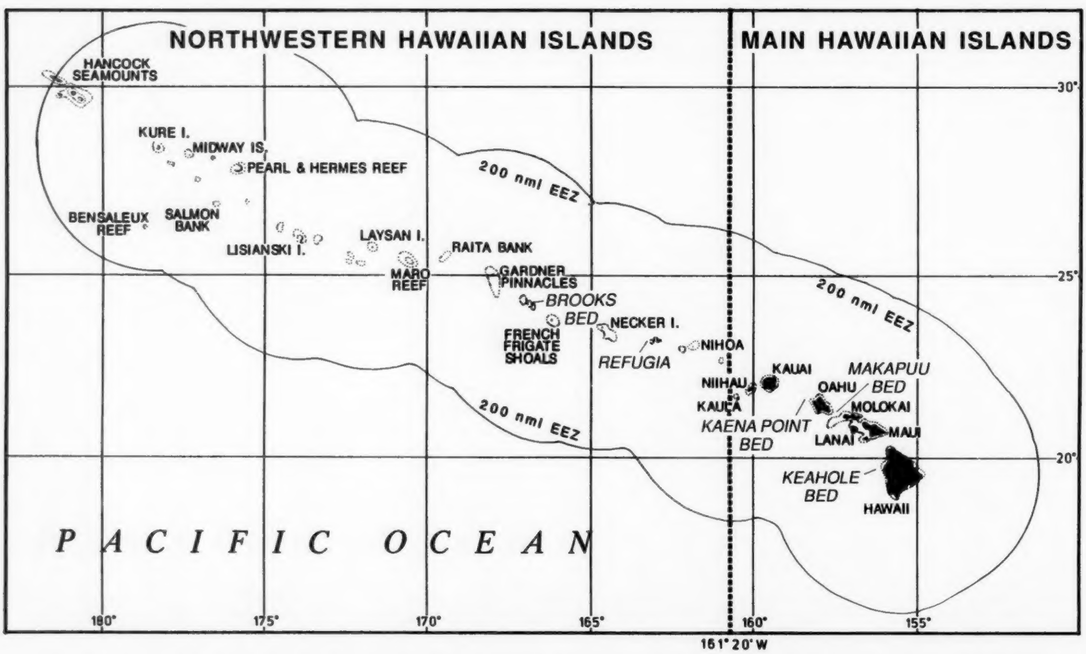

Figure 6.—Map of the EEZ in the southern half of the Hawaiian Archipelago showing the location of five precious coral beds.

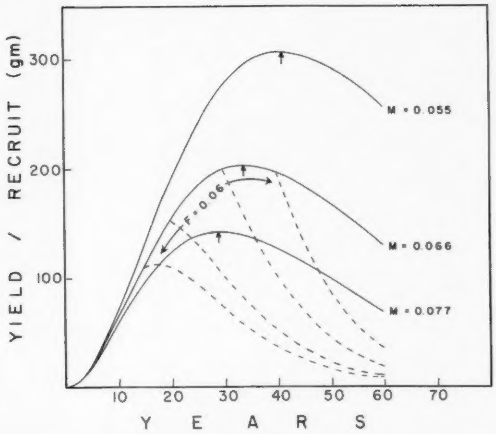

Figure 7.—The Beverton and Holt yield-per-recruit model was used to estimate MSY (vertical arrows) for *Corallium secundum* in the Makapuu coral bed at 3 different values of natural mortality. Dashed lines indicate yield curves produced by applying a fishing mortality of 0.06 at four different ages.

cated. There are four exploratory permit areas; one surrounding the Hawaiian Islands, another that encompasses Guam and the Commonwealth of the Northern Marianas, a third that encircles American Samoa, and a fourth, which was created by Amendment 1 to the FMP, which includes the EEZ's of all the remaining U.S. Pacific Island possessions. Either selective or nonselective harvest gear is permitted in exploratory permit areas except in the Hawaii exploratory area around the Main Hawaiian Islands.

Specific weight quotas and size limits have been determined based on estimates of maximum sustainable yields and optimum yields. For example, the established bed at Makapu'u has a 2-year harvest quota for selective gear only: 2,000 kg for *C. secundum*, 600 kg for *Gerardia* sp. and 500 kg for *L. olapa*. Only colonies of *C. secundum* taller than 10 inches can be harvested. Quotas of 1,000 kg of all species of precious coral combined, exist for each of the EEZ exploratory areas. Foreign fishing is allowed in exploratory areas, if the quotas are not taken by domestic fishermen. Maximum sustainable yields were calculated by using the Beverton and Holt cohort production model (Beverton and Holt, 1957) for *Corallium secundum* (Fig. 2, 7) and the Gulland Model (MSY = 0.4 *M Bo*) where *m* = natural mortality and *Bo* is the virgin biomass, for *Gerardia* and *Lepidisis*.

Having described the management measures established to conserve precious coral resources in Hawaii and the Western Pacific, it is important to evaluate their effectiveness over the history of the fishery. For pink corals, management efforts have been successful for the domestic fishery; however, poaching by foreign fishing has frequently occurred within the U.S. EEZ and is difficult to control.

Considering the domestic coral fisheries first, the cumulative harvest of *Corallium* from the Makapu'u bed between 1966 and 1978 was about 32% of the standing stock. The average annual harvest was 685 kg, somewhat less than the best estimate of MSY, near 1,000 kg. Surveys of the Makapu'u bed in 1983 and again in 1985 showed substantial recovery at rates in close agreement with model predictions in the FMP (Grigg, 1988). For black coral, the combined MSY for beds off Maui and Kauai is 6,250 kg/yr (Grigg, 1976). Harvest levels of black coral above MSY occurred only in the earliest years of the fishery (Table 3) and supply has always been unable to meet demand. Only the most accessible black coral beds off Lahaina, Maui, have been depleted.

Foreign poaching has been a serious problem in the past. During the 1980's, Japanese and Taiwanese coral vessels continuously violated the EEZ near the Hancock Seamounts. In 1985, about 20 Taiwanese coral draggers reportedly poached about 100 tons of *Corallium* from seamounts within the EEZ north of Gardner Pinnacles and Laysan Island. Absence of poaching since that time could indicate that the resources in these areas have been economically exhausted. A research program is currently planned to resurvey the Hancock Seamounts in 1994 with the University of Hawaii research submersible *Pisces V*, in order to assess the present condition of precious coral resources in this area.

Research Needs and Future Prospects

The most pressing need of the precious coral fishery (and industry) is stock assessment; first in order to describe the status of the stocks within established grounds, and second, to discover new areas. Without substantial efforts to explore and discover new grounds, the precious coral fishery will undoubtedly continue to decline. The problem will become increasingly more serious as existing stockpiles accumulated during the early 1980's are gradually exhausted.

The most promising exploratory areas appear to be in southern oceans. Channel waters around Madagascar and Tasmania (Grigg and Brown, 1991) are particularly promising areas and scattered occurrences of large colonies of *Corallium* spp. have been reported (exact locations are well guarded secrets). Considerable exploration has been conducted in the tropical Pacific by CCOP-SOPAC (Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas), and *Corallium* spp. have been recorded from many localities (Cook Islands, Fiji, Kiribati, Solomon Islands, Tonga, Vanuatu, and W. Samoa), but unfortunately not in commercial quality or abundance

(Harper, 1988). Most exploratory dredging by CCOP-SOPAC, however, has been at depths between 200 and 500 m, and virtually nothing is known about the potential of deeper water resources (such as *Corallium* sp. nov. which occurs at a 1,000–1,500 m depth by the Emperor Seamounts).

Another important research question concerns recovery rates (recruitment and growth) in areas which have been heavily harvested. A proposal to assess the stocks on the Hancock Seamounts using the *Pisces V* submersible has been accepted by the Hawaii Undersea Research Laboratory at the University of Hawaii and is presently scheduled for the summer of 1995. The whole area of population dynamics of precious corals is in need of further research.

The mariculture of precious corals is an exciting new area of research. A new laboratory for the biological, economic, and technical research of precious corals has recently been established in Kochi, Japan, in order to attempt the culture of precious coral (Sadao Kosuge, Director of the Institute of Malacology, Tokyo. Personal commun. 1992). To date, colonies of *Corallium japonicum* have been maintained alive in culture for over one year but growth rates are very slow and colonies have not been induced to reproduce. However, the research is still in a very early stage.

While a complete analysis of the economics of the precious coral fishery is beyond the scope of this paper, it is important to mention that this is another area in need of future research. The worldwide glut of *Corallium* precious coral produced during the boom years of the early 1980's caused prices to fall sometimes even below break-even costs for Taiwanese and Japanese coral fishermen and many vessels dropped out of the fishery during this time. The future supply of *Corallium* to the Hawaiian industry will probably continue to depend on exports from these countries; therefore, what happens to the Japanese and Taiwanese fleet is important. Exploration is very expensive and there appears to be little Japanese or Taiwanese interest in wide ranging fishing expeditions at the present time. For this reason, the future of the industry can only be described at this juncture as uncertain. Prices will undoubtedly continue to climb. The raw material for Midway deep-sea coral is still (1990) reasonable at about $150/kg but prices for high quality pink and red *Corallium* peaked in 1990 at $3,069/kg and $16,103/kg, respectively (D. Ancona, U.S. Embassy, Tokyo. Personal commun. 1991). The future of the industry would appear to depend on either successful future exploration or a breakthrough in the mariculture of precious corals.

As for the future of the black coral fishery, at least in Hawaii, it appears to be secure in terms of both supply and demand for the resource. The management of other species of precious coral in Hawaii and the Western Pacific will continue to be covered by the existing FMP of WESTPAC. Regarding the control of foreign fishing in international waters, it is in the best interest of the United States, Japan, and Taiwan to enter into an international treaty for the purpose of conservation of precious corals. However, before this can be achieved, an impetus for such implementation must be initiated by one or all three countries. Based on the principle of common heritage embodied in the International Law of Sea (LOS) convention, and on articles of the LOS Treaty which urge agreements between member countries on measures to conserve living resources within and beyond EEZ's, the Western Pacific Fishery Council has requested that the U.S. State Department enter into multilateral arrangements with Japan and Taiwan for jointly managing the precious coral fisheries in the Pacific.

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The Development and Decline of Hawaii's Skipjack Tuna Fishery

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Introduction

Historically, the pole-and-line, live-bait fishery for skipjack tuna, *Katsuwonus pelamis*, was the largest commercial fishery in Hawaii. Annual pole-and-line landings of skipjack tuna exceeded 2,500 metric tons (t) or 5.5 million lb from 1937 to 1973 (June, 1951; Yamashita, 1958; Uchida, 1976; Skillman, 1987; Kikkawa[1]), except during World War II (1941–45). The record production of 7,400 t (16.3 million lb) of all species landed in 1965 by the pole-and-line fishery was unsurpassed until 1991, when the Hawaii longline fishery landed 8,000 t (all species combined). Even so, at its largest, the Hawaii skipjack tuna catch was small compared with the total Pacific catch of this species (ca. 870,000 t in 1990; IATTC, 1992; Hampton, In press).

The Hawaii skipjack tuna fishery originally supplied only the local market for fresh and dried tuna. The fishery expanded in the 1900's because the ready availability of skipjack tuna was sufficient to support a cannery which provided access to outside markets. A sustained drop in the catch per unit effort (CPUE) of large (>6.8 kg, >15 lb) skipjack tuna began in 1974. The decrease in CPUE was related to environmental changes affecting local fish availability (Mendelssohn[2]; Boggs, 1988). Combined with increased fishing costs, market competition from other tuna products, and the 1984 closure of the Hawaiian Tuna Packers, Ltd. cannery in Honolulu, these factors caused a major decline in Hawaii's skipjack tuna fishery during the late 1970's and 1980's (Boggs and Pooley, 1987; Hudgins and Pooley, 1987). The fishery has not recovered.

Expanding fisheries for skipjack tuna throughout the Pacific (Forsbergh, 1980; IATTC, 1992; Hampton, In press) do not appear to have caused the decline in Hawaii's fishery (Boggs and Pooley, 1987; Kearney, 1987; Sibert, 1987), although further analyses may reveal negative impacts. Skipjack tuna are relatively impervious to overfishing (Boggs and Pooley, 1987; Hampton, In press) due to widespread distribution and reproduction, rapid growth, early maturity (Matsumoto et al., 1984), and frequent spawning (Hunter et al., 1986). Unlike populations of larger tuna species (Miyabe, In press; Suzuki, In press) and marlins (Suzuki, 1989), skipjack tuna appear to be underexploited (Kleiber et al., 1983; Hampton, In press). The absence of regulation in Hawaii's skipjack tuna fishery contrasts with the management of Hawaii's fisheries for other tunas and billfish (Boggs and Ito, 1993), and is justified by the apparent underexploitation of the stock and the declining size of the local fishery.

This review describes the Hawaii skipjack tuna fishery, its development through the 1970's, and subsequent decline. Research on factors contributing to the decline are summarized and the fishery community's attempts at revitalization are described.

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ABSTRACT—The pole-and-line fishery for skipjack tuna, Katsuwonus pelamis, *was the largest commercial fishery in Hawaii until its decline in the 1970's and 1980's. The development and decline of the fishery were strongly affected by fish availability and marketing. A sustained drop in the availability of large fish in the mid-1970's appears to have been due in part to a sustained environmental change. Availability of large fish subsequently increased, but the fishery continued its decline owing to low profitability and lack of markets. The tuna cannery in Honolulu that fostered the fishery's expansion in the 1930's closed in 1984. Unless efforts to increase the market for skipjack tuna become effective, landings will probably remain at current levels of about 1,000 metric tons per year. The existing pole-and-line fleet may continue to decline with age, and the local market may eventually be supplied by other fishing methods (e.g., trolling), by new vessels, or by imports.*

Description and Historical Development

In Hawaii, skipjack tuna, commonly called by its Hawaiian name "aku," is mostly caught by pole-and-line fishing (e.g., >99% through 1974, 72% in 1990). This method uses live bait thrown from a fishing vessel to stimulate a surface school into a feeding frenzy. Fishing is then conducted frantically to take advantage of the limited time the school remains near the boat. The pole and line are of equal length (ca. 3 m) and are used with a barbless hook with feather skirts which is slapped against the water until a fish strikes. Then the fish is yanked into the vessel in one motion. The fish unhooks when the line is slacked so that the process can be repeated.

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The bait most often used is the anchovy *Encrasicholina purpureas*, commonly called by its Hawaiian name "nehu." Each fishing vessel seines for bait in bays, harbors, and other sheltered waters, and the bait is not "hardened" for long-term transport or for use more than a few days after capture. The fishery is limited to areas close to the eight main Hawaiian Islands. Skipjack tuna are located by searching for bird flocks associated with surface schools. Fishing trips seldom last longer than a day, and most vessels return to port each night.

The basic pole-and-line method in use today was practiced in the 1800's largely by native Hawaiians using canoes (June, 1951). In 1900 the fishery was relatively small, with total landings of 190 t (0.4 million lb, Fig. 1) sold in the fresh market (Yamashita, 1958). Around the turn of the century Japanese immigrants began introducing small (ca. 6 m) shallow-draft wooden sampans with built-in bait wells, followed by motor powered vessels starting in 1907. In the 1930's the vessels were redesigned to be larger, with deeper draft, flying bridges, pump-spray systems, and greater freeboard forward to give them better seaworthiness (June, 1951). Pump-spray systems agitate the water around the vessels during fishing. To the fish, the agitated water may resemble a school of bait and partly obscure the view of the boat and fishermen.

The Hawaiian Tuna Packers, Ltd. cannery in Honolulu was established in 1917, enabling the fishery to expand beyond a relatively small fresh and dried market. The greatest annual amount sold in the fresh and dried market was 2,200 t (4.9 million lb) in fiscal year 1935 (i.e., July 1934–June 1935, Yamashita, 1958). The market for canned product allowed the fishery to expand to a peak of 6,100 t (13.4 million lb) in 1940 (Fig. 1) followed by a hiatus during WWII. From 1937 until the early 1980's most of the skipjack tuna landed in Hawaii was canned.

Before WWII the fishery included up to 26 vessels (Hudgins and Pooley, 1987) and landed an average of 5,000 t (2.3 million lb) per year from 1937 to 1940. Most vessels constructed before WWII averaged about 31 t displacement and had a bait-well capacity below 3,000 L (800 gallons, defined as Class I vessels). Larger sampans, averaging 58 t, were mostly built in the late 1940's and 1950's. These generally had a bait-well capacity greater than 3,000 L (defined as Class II vessels, Uchida, 1976; Kikkawa[1]).

As new vessels were built, fleet size increased to a maximum of 32 vessels in 1948. The prewar landings record was surpassed in 1954 (Fig. 1). During the 1950's through the early 1970's the fleet landed an average of about 4,000 t per year. Interannual variation in catch was large, but no significant long-term trend was apparent from 1948 to 1970 (Uchida, 1976).

Total catch levels remained high despite a decline in fleet size from 32 to 15 vessels between 1948 and 1971 because 1) fishing efficiency increased as the proportion of Class II vessels in the fleet increased, and 2) the number of days fished per boat increased (Uchida, 1976). As a result, total standardized effort in the 1970's averaged only slightly below that in the 1950's (Uchida, 1976; Skillman, 1987; Kikkawa[1]) (Fig. 2).

From the 1970's to the present most of the active vessels have been the remaining wooden-hulled sampans built in the 1940's and 1950's. These vessels carry crews of 7–9 fishermen, and frequently work 6 days a week. The work is arduous and may begin with bait seining at dawn followed by fishing to dusk. One new steel-hulled vessel with about twice the displacement (91 t) of the old wooden vessels entered the fishery in the 1970's, but was not very successful.

The Decline

Since the mid-1970's the trend in Hawaii skipjack tuna landings has been downward (Fig. 1), reflecting both a decline in fishing effort (Fig. 2) and CPUE (Fig. 3). Current (1990–91) annual landings average <1,000 t (2.2 million lb) (Ito[3]). By the mid 1980's the number of vessels in the fishery had fallen to nine (from 15 in 1971) and in 1991 only six vessels were active, four active on a full-time basis. Fishing effort dropped after 1979, falling to 1,023 Class II fishing days in 1981 and 922 days in 1986 (Fig. 2). Another major drop in fishing effort occurred in 1989–90 (Ito[3]) and 1991 effort was only 553 fishing days (Fig. 2). Fishing effort data for 1948–83

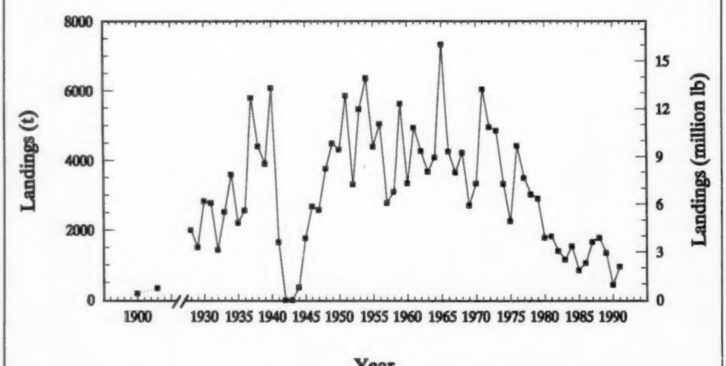

Figure 1.— Total annual skipjack tuna landings in metric tons (t) and pounds (lb) by the pole-and-line fishery in Hawaii, 1900–91. Sources: 1900–47 from Yamashita (1958); 1948–70 from Uchida (1976); 1970–83 from Kikkawa[1], 1984–85 from State of Hawaii Division of Aquatic Resources; 1986–87 from Pooley[4], and 1988–91 from Ito[3].

[3]R. Y. Ito. 1992. Western Pacific pelagic fisheries in 1991. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-92-15, 38 p.

Figure 2.— Total annual fishing effort (in days) by the pole-and-line fishery in Hawaii, 1948–91. Effort data for 1948–83 and 1986–87 are standardized (Uchida, 1976; Kikkawa[1]). Sources as given in Figure 1.

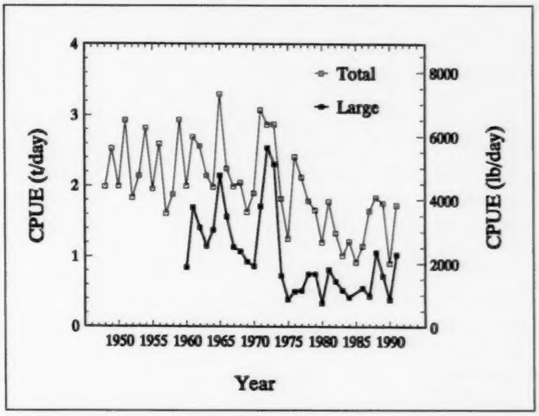

Figure 3.— Annual skipjack tuna CPUE in metric tons (t) and pounds (lb) per vessel per day for all sizes (total) and large fish (>6.8 kg or 15 lb), 1948–91. Sources as given in Figures 1 and 4.

(Uchida, 1976; Kikkawa[1]) and for 1986–87 (Pooley[4]) were standardized (Fig. 2) to account for zero-catch trips and relative efficiency (Class I versus Class II). Data for 1984–85 and 1988–91 were summary statistics without the information required for standardization. The importance of standardization was minimal after 1987 because the 1988–91 data included zero-catch trips and contained primarily Class II fishing days.

Catch rates (CPUE in t/Class II fishing day) exhibited a declining trend in the 1970's and 1980's (Fig. 3). The high degree of interannual variability in CPUE was typical of geographically restricted surface fisheries for skipjack tuna, but the declining trend was unusual. In particular, the drop in CPUE for large (>6.8 kg, >15 lb) skipjack tuna in 1974 was extreme and was sustained though 1987 (Fig. 3).

Large (>6.8 kg) skipjack tuna historically represented over 50% of the Hawaii landings by weight (Fig. 4). None of the world's major skipjack tuna fisheries depend on such large fish to supply the bulk of their catch. Large skipjack tuna command higher prices in both the fresh fish and cannery markets. From a high of over 80% in 1972–73 the proportion of large fish in Hawaii landings fell to a low of 40% in 1974 and remained below 40% through 1977 (Fig. 4). Reduced landings of large fish resulted in a substantial decrease in profitability to the pole-and-line fishery (Hudgins, 1987). The proportion of large fish in the catch has shown an upward trend since 1977 but has only exceeded 50% in a few years (1983, 1988, and 1991, Fig. 4).

The distribution of fishing effort by the fleet also changed in the 1970's. At the height of the fishery in the 1950's and 1960's, several vessels were based on the islands of Hawaii and Maui, and sizable catches came from the northeast coasts of these islands (Uchida, 1970). In the 1970's and 1980's most of the catch came from areas around Oahu, Kauai, Molokai, and Lanai (Kikkawa[1]). Presently all of the vessels work out of Kewalo Basin or Kaneohe Bay on Oahu.

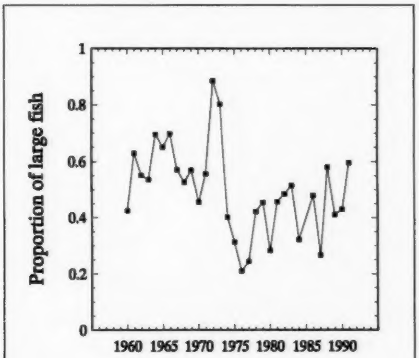

Figure 4.— The proportion of large (>6.8 kg or 15 lb) fish in annual skipjack tuna landings by the pole-and-line fishery in Hawaii, 1960–91. Sources for size composition of catches: 1960–84 and 1986–87 from Pooley[4] and 1988–91 from Ito[3].

[4]S. G. Pooley. NMFS shore-side sampling program. Honolulu Lab., Southwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 2570 Dole St., Honolulu, HI 96822–2396, unpubl. data.

Increasing age of the fishing fleet and rising fuel prices may have contributed to more conservative fishing practices in the 1970's and 1980's, resulting in fewer trips taken far from land. In the 1970's skipjack tuna pole-and-line vessels also began to fish around fish aggregating devices (FAD's), in addition to the more traditional practice of scouting for bird flocks to locate fish. If large skipjack tuna were more common farther offshore, a greater frequency of nearshore trips might have contributed to the decreased catch of large fish. Uchida and Sumida (1971) found the average size of skipjack tuna caught by 7 vessels in the summer of 1967 was smallest in areas closest to Oahu.

Changes in the geographic distribution of fishing effort in the 1970's appear to have affected overall CPUE, which was consistently higher than average for oceanic areas, defined as more than 37 km (20 n.mi.) from shore (Uchida, 1966, 1970, 1976). The catch from oceanic areas averaged about 25% of the total catch from the 1950's through the early 1960's (Uchida, 1966). From 1974 to 80 catches from oceanic areas averaged only about 20% of the total catch (Kikkawa[1]). Data on the distribution of the catch in more recent years have not been summarized.

The cannery closed in 1984 because of economic restructuring in the global tuna industry and because of market constraints (King, 1987). The decline in Hawaii skipjack tuna landings contributed to the problems of the cannery but was not directly responsible for its closure. This pivotal event left the fishery with only a local, fresh and dried fish market. Previously, the fishery had been highly seasonal; summer (May–September) landings averaged about 400 t (900,000 lb) per month accounting for about 70% of annual landings (1964–82 average, Hudgins[5]). However, the fresh fish market absorbed only about 140–200 t (300,000–450,000 lb) per month after the cannery closed, reducing summer landings to about 54% of annual landings (1986–87 average, Pooley et al.[6]).

The decline of the Hawaiian domestic pole-and-line fishery roughly coincided with increases in skipjack tuna landings by the domestic troll fishery in Hawaii. The amount of skipjack tuna caught by domestic longline and handline fisheries in the Hawaii Exclusive Economic Zone (EEZ) has always been relatively insubstantial, but commercial troll catches increased from <1% of Hawaii's total skipjack tuna landings in the early 1970's to 10% in 1985 and to about 20% in 1990 and 1991. Expressed as a percentage, this increase is partly due to the decline in pole-and-line landings, but troll landings did increase from <50 t (<0.1 million pounds) in the early 1970's to >200 t (>0.5 million pounds) in 1991 (Boggs and Ito, 1993).

Pole-and-line vessels from Japan fishing for skipjack tuna within the EEZ surrounding the Northwestern Hawaiian Islands also increased their catches during the decline of Hawaii's domestic pole-and-line fishery. Foreign fishing effort increased from 213 to 767 vessel-days from 1972 to 1977, while foreign catch increased from 1,000 to 4,600 t (Yong and Wetherall, 1980). From 1978 to 1984 the annual catch in the EEZ by the foreign fishery ranged from 2,000 to 4,000 t, reaching twice the level of the domestic catch (Boggs, 1987). No foreign data have been obtained since 1984, but this fishery continued to operate legally in the EEZ through 1992. New regulations may discourage the continuation of this fishery in 1993.

Causes for the Decline

Bait Problems

A lack of bait during certain times of the year is frequently cited as a problem by Hawaii fishermen. The CPUE (catch per trip) for bait fish in the 1970–81 period (Kikkawa[1]) averaged slightly (ca. 4%) higher than in the previous decade (Uchida, 1977) but showed a declining trend. In 1986–88, bait fish CPUE in Pearl Harbor averaged 27% lower than that in 1970–81 (Kobayashi[7]). These modest declines (1970–81, 1981–86) in bait fish CPUE may have contributed to the problems of the pole-and-line fishery but were not viewed by industry participants as a direct cause for the decline of the fishery (Boggs and Pooley[8], 1987).

A more serious problem for some vessels has been the high cost of the vessel insurance required for entering U.S. military areas (i.e., Pearl Harbor) to catch bait (Boggs and Pooley[8], 1987). Alternatives to the harvest of wild bait by each individual vessel have been proposed (Shug and Shang[9]), but Hawaii fishermen are very resistant to purchasing bait, especially when wild bait is available. Under present conditions, the rearing or importation of bait fish would be stop-gap measures and would not be economically feasible (Shug and Shang[9]).

Fish Availability

Owing to the small scale of Hawaii's skipjack tuna fishery, local fishing pressure is not likely to affect the availability of skipjack tuna in Hawaii. Uchida (1976) showed that in Hawaii, changes in CPUE were not associated with changes in local fishing intensity at a time when the local catch was much higher than it has been in recent years. The increase in pole-and-line catches by foreign vessels in the Hawaii EEZ in the 1970's roughly coin-

[5]L. L. Hudgins. 1986. Economic issues of the size distributions of fish caught in the Hawaiian skipjack tuna fishery 1964–82. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-86-14, 16 p.

[6]S. G. Pooley, S. Teramoto, and A. C. Todoki. 1988. Hawaii's aku boat fishery in 1986 and 1987. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-88-16, 15 p.

[7]D. R. Kobayashi. Honolulu Lab., Southwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 2570 Dole St., Honolulu, HI 96822-2396, unpubl. data.

[8]C. H. Boggs and S. G. Pooley. 1987. Strategic planning for Hawaii's aku industry. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-87-1, 22 p.

[9]D. M. Shug and Y. C. Shang. 1983. An economic feasibility study of culturing topminnows as an alternative baitfish for skipjack tuna fisheries in Hawaii, American Samoa, Guam, and the Northern Mariana Islands. Pacific Business Center, University of Hawaii, Honolulu, HI 96822. Econ. Dev. Admin., Tech. Assist. Proj. Rep., 32 p.

cided with the decline of Hawaii's pole-and-line fishery (Boggs, 1987), but there was no significant correlation between annual catch by the foreign fishery in the EEZ and domestic CPUE (r = -0.34, p >0.25, N = 13) for years with available data (1972–84).

More research is needed to establish whether the Pacific-wide increase in catch from <500,000 t in 1980 to almost 900,000 t in 1990 (IATTC, 1992; Hampton, In press) has affected the availability of skipjack tuna to Hawaii fishermen. The evidence suggests major increases in catch have had no effect on relative abundance, as indicated by CPUE in large-scale fisheries. For example, the largest catch and the greatest increase in catch was in the western Pacific, where a doubling of the catch from 1980 to 1990 had no perceptible impact on CPUE in that region (Hampton, In press). Declining abundance might have been obscured by improvements in fishing efficiency that increase CPUE (Hampton, In press). However, tagging experiments in the western Pacific also suggest that skipjack tuna are too productive to be affected by current levels of harvest (i.e., <1 million t). Kleiber et al. (1983) estimated a western Pacific biomass of skipjack tuna on the order of 3 million t and a turnover rate of 6 million t/year. These studies (Kleiber et al., 1983; Hampton, In press) imply that the decline in Hawaii CPUE was not caused by a decline in the abundance of skipjack tuna in the western Pacific.

Some genetic evidence suggests that skipjack tuna in Hawaii are part of a central and eastern Pacific stock that is partially isolated from the western Pacific resource (Matsumoto et al., 1984; Kearney, 1987). Tagging experiments in the eastern Pacific have resulted in tag recoveries in Hawaii, whereas western Pacific tagging experiments have not (Kearney, 1987). Therefore, the decline in Hawaii's CPUE (Fig 4) might logically be attributed to a corresponding increase in eastern Pacific skipjack tuna catches (Hudgins[5], 1987) which exceeded previous (1960–74) levels in 1975 and remained higher than average through 1982 (IATTC, 1992). However, the timing of this increase could not correctly explain the decline in catches in Hawaii a year before (in 1974). Moreover, eastern Pacific catches subsequently declined (1983–90, IATTC, 1992) without a corresponding increase in Hawaii's CPUE (Kearney, 1987). Furthermore, CPUE in the eastern Pacific seems to be unaffected by harvest level (IATTC, 1992).

If there was a negative impact of the eastern Pacific fishery on Hawaii's fishery, it would most likely take effect after a time lag to give eastern Pacific fish time to reach Hawaii and to grow to the size harvested by Hawaii's fishery (Kearney, 1987). A significant (r = 0.54, p <0.05, N = 30 years) negative correlation has been found between the Hawaii catch of skipjack tuna and the total catch (of all sizes) in the eastern Pacific one year earlier (Ianelli[10]). However, a better indicator of interaction between these fisheries would be a significant negative correlation between CPUE (rather than catch) in Hawaii and the eastern Pacific catch in the preceding year. No such correlation has been found (Kearney, 1987; Ianelli[10]).

The unusual dependence of Hawaii's skipjack tuna fishery on large fish means that it is more sensitive to changes in fish population size structure than the large-scale fisheries of the eastern and western Pacific. A reduced size-frequency distribution of the population due to increasing harvests by large-scale fisheries might not be reflected in the CPUE of those fisheries but still affect availability of large skipjack tuna in Hawaii (Boggs, 1987). Eastern Pacific skipjack tuna size-frequency distributions show decreasing average size from 1972 to 1981 followed by increasing average size through 1985 (IATTC, 1985, 1992). This sequence does not correspond closely with Hawaii's abruptly reduced proportion of large fish in 1974, or the increasing trend after 1977 (Fig. 4). Further analyses of these data are being conducted (Ianelli[10]). In the western Pacific, improved collection and analysis of size-frequency data are needed for evaluation of fishery interaction (Hampton, In press).

Annual time series of skipjack tuna catch in Hawaii have been found to be correlated with sea surface temperature (Jones[11]) and salinity (Seckel, 1972). Various models have been used to predict annual catches based on these environmental variables (Mendelssohn[2]; Boggs, 1988, 1989). The most recent model based on sea surface temperature (Boggs, 1988) explained 68% of the variation in the CPUE of large skipjack tuna during 1960–83 (Fig. 5). This model suggests that a sustained decline in CPUE for large skipjack tuna after 1973 was related to a sustained change in spring sea surface warming patterns east of Hawaii.

Spring warming patterns reflect the relative strength and northward extent of the California current extension (CCE) which joins the North Equatorial Current (NEC) near Hawaii. An hypothesis is that the CCE and NEC provide a conduit for immigration of large skipjack tuna from the eastern tropical Pacific to Hawaii (Seckel, 1972; Boggs, 1988). The most recent models also involve a time lag (Mendelssohn[2]; Boggs, 1988) which could reflect relationships between temperature and recruitment, mortality, or migration in preceding years. Previous models (e.g., Seckel, 1972) explained variation in Hawaii CPUE based on the proximity of the north edge of the CCE or NEC as measured by sea surface temperature and salinity in Hawaii, but these models eventually failed to provide good predictions when the north edge of the current passed north of the islands (Skillman[12]).

The spring warming model (Mendelssohn[2]; Boggs, 1988) was used to predict CPUE for large skipjack tuna during 1984–90 and indicated that the availability of large skipjack tuna

[10] J. Ianelli, Fisheries Research Institute, Univ. Wash., Seattle, WA 98195. 1992, personal commun.

[11] E. C. Jones. A winter index of Hawaiian skipjack tuna catch. Honolulu Lab., Southwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 2570 Dole St., Honolulu, HI 96822–2396, unpubl. manuscr.

[12] R. A. Skillman, Honolulu Lab., Southwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 2570 Dole St., Honolulu, HI 96822–2396. 1991, personal commun.

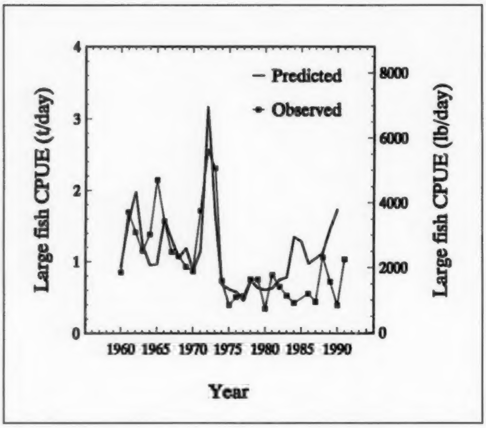

Figure 5.— Annual skipjack tuna CPUE in metric tons (t) and pounds (lb) per vessel per day for large fish (>6.8 kg or 15 lb), 1960–91, compared with CPUE predicted by an environmental model. Sources as given in Figures 1 and 4.

around Hawaii should have returned to pre-1974 levels after 1983 (Fig. 5). Although the proportion of large fish in the Hawaii catch returned to 1960–73 average levels in 1988 and 1991 (Fig. 4), the CPUE for large skipjack tuna in recent years has remained much lower than predicted (Fig. 5).

Three factors that may have contributed to lower-than-predicted CPUE after 1983 were 1) a self-imposed quota employed by vessels to avoid flooding a limited market, 2) reduced scouting and fishing closer to port, and 3) a change in the overall age structure of the population because of increased fishing pressure elsewhere in the Pacific. The first two factors are economic, and could result in reduced CPUE without any change in fish abundance. For example, CPUE is biased downwards by a self-imposed quota (factor 1) because measures of effort (days) and CPUE (catch per day) do not account for trips of less than a day when a quota is achieved early in the day. Increased fishing near shore (factor 2) would decrease CPUE because average CPUE is highest >37 km from shore (Uchida, 1966, 1970, 1976) and fish may be smaller than average near shore (Uchida and Sumida, 1971). Existing analyses do not indicate that the availability of large fish has been reduced by the impacts of fishing on population age structure (factor 3) but further study is needed.

Economic Causes of the Decline

One economic factor in the continuing decline in total catches after 1974 (Fig. 1) was a negative correlation between catch and the price of fuel (Hudgins[5]). In a comparison of catches for 1982 with those for 1974, the decrease in annual catch attributable to fuel price increases was estimated to have reduced annual revenue by \$1.3 million. Over this same period, a decrease in catch attributable to reduced CPUE and a low proportion of large fish in the catch (Fig. 4) were estimated to have reduced annual revenue by \$1.0 and \$0.36 million, respectively (Hudgins[5]). These losses represent over 50% of potential revenue; actual revenue was only \$2.5 million in 1982 (Pooley et al.[6]).

The mechanism by which fuel price increases affect the catch has not been documented, but the fuel price rise that began in 1973 did not immediately affect the total number of fishing days (Fig. 2). Perhaps expensive fuel and poor maintenance on some vessels result in restricted scouting for schools of fish and in fishing closer to land. Fishing around FAD's may increase the proportion of small fish in the catch (Boggs and Pooley, 1987), but FAD fishing seems to be mostly a last resort when schools of larger fish cannot be located. Small fish landings increased in 1976 whereas FAD's were not fully deployed until 1980 (Hudgins[5], 1987).

Declining profitability has played an important role in the decline of the fishery (Pooley, 1987). Low earnings since the 1960's curtailed investment in new boats. Attempts to increase profits by selling more high-priced, fresh skipjack tuna faced market limitations even before the cannery closed. During 1970–85 the price per ton rose 45%, but costs rose 75% (after inflation). To offset fuel (200%) and insurance (390%) cost increases, the share of profit paid to crews was kept low, and repairs were postponed (Pooley, 1987). Poor maintenance resulted in frequent breakdowns and safety problems. Five vessels which sank during the 1980's and 1990's have not been replaced. Such problems may have influenced the fleet's fishing range, resulting in fewer fishing trips to more productive oceanic areas. Now, most of the vessels still remaining in the fleet are well maintained.

An increase in troll, handline, and longline landings of yellowfin and bigeye tunas during the 1970's and 1980's resulted in competition for the fresh tuna market, reducing the available market for skipjack tuna after the cannery closed. Although skipjack tuna is priced lower than yellowfin tuna (on average) and is appreciated by Hawaii residents in raw, cooked, and dried product forms, it is not widely accepted in the local restaurant (tourist) or export markets. In 1985 the average ex-vessel price for skipjack tuna was only \$2.48/kg (\$1.13/lb), whereas the average price for yellowfin tuna was 26% higher. The price difference has increased along with prices, and in 1991 the average yellowfin tuna price of \$4.98/kg (\$2.26/lb) was 58% higher than the average skipjack tuna price. Yellowfin tuna can readily be sold to the restaurant market in Hawaii or exported, and it has a much longer shelf life than skipjack tuna. Yellowfin and bigeye tuna are preferred over skipjack tuna for sashimi in the export mar-

kets. Flash-frozen skipjack and yellowfin tuna imported to Hawaii from Japan also competes with the Hawaii fishery for a share of the local market. The flash-frozen product is acceptable for sashimi, although it can be distinguished from fresh skipjack tuna.

The closure of the Honolulu tuna cannery in 1984 cost the skipjack tuna fishery an estimated $0.5 million (18%) in annual sales, and the loss would have been much worse had the fishery not already been so reduced (Hudgins, 1987). The most pronounced effect of the closure has been to discourage revitalization of the fishery. The lack of a cannery market is especially troublesome during the summer when the skipjack and yellowfin tuna fisheries reach peak production. As a result, pole-and-line vessels occasionally experienced severe market competition and devastating price reductions in the 1980's (Boggs and Pooley, 1987).

Self-imposed catch limits are now employed by Hawaii pole-and-line vessels to avoid flooding the limited fresh-fish market, especially on trips made during summer when fish are most available (Boggs, 1988, 1989). Incorporation of a monthly limit to landings with an environmental model (Boggs, 1988) produced more realistic predictions of CPUE and annual catch (Boggs, 1988, 1989). Since summer is also the season when large fish predominate in the catch, self-imposed quotas contribute to a lower proportion of large fish on an annual basis.

In summary, Hawaii's pole-and-line fishery was economically stressed throughout the 1970's and 1980's because of rising costs and reduced profitability (Pooley, 1987). Then from 1974–83 the availability of large fish declined because of environmental changes (Mendelssohn[2]; Boggs, 1988) and the fishery declined. Models based on environmental factors predict increased availability since 1983 but CPUE has remained low. Reasons for continuing low CPUE may include self-imposed quotas and fishing closer to shore than in the past. No clear evidence indicates that overfishing has had a negative impact in Hawaii or elsewhere in the Pacific. The fishery has not recovered owing to continued high costs, low profits, and a limited market.

Remedies and Future Prospects

A workshop and a strategic planning process (Boggs and Pooley[8], 1987) were conducted in Honolulu in 1986 to discuss causes of the fisheries decline and remedial actions. An expanded market and products with a long shelf life to absorb peak production during the summer were seen as the most important objectives for revitalizing the fishery. A group of investors purchased the cannery facility in 1985 with the intention of integrating it into a marine-oriented tourist center but the cannery has not reopened. Making tuna canning profitable in Hawaii would require promotion of specialty packs that appeal to tourists and local residents, because production of normal canned tuna in Hawaii is too expensive to compete on the world market (King, 1987).

The available evidence indicates that the skipjack tuna population can easily support an expanded fishery in Hawaii, although the fishery would remain vulnerable to an environmentally driven reduction in availability like that of 1974–83. If ocean-wide fishing pressure has had an impact on availability, local (EEZ) management would not substantially ameliorate that impact because the local fishery is relatively small. Bait fish stocks would be the only resources that might require local management if the fishery were to expand. These stocks were sufficient in the 1970's to support three times the number of full-time vessels currently active. The modest decline of bait fish stocks (ca. 27%) since the 1970's might become a limiting factor if the fishery were to more than double its present size. If the profitability of the fishery increased, it might be able to support a bait fish culture industry (Shug and Shang[9]).

The future of the fishery depends primarily on the development of markets. The State of Hawaii has conducted market expansion projects and supported experiments to try and increase product shelf life, but these have not been very successful, in comparison with similar efforts in promoting other species. Expansion of the market will likely require innovative product technology that can economically preserve summer catches for later sale or fishing technology that will permit increased catches during the season of low availability.

In 1986 Hudgins (1987) predicted that without new markets, economic competition would force all but 4 or 5 of the most efficient Hawaii skipjack tuna fishing vessels out of business. She predicted that these vessels would supply about 900 t (2 million lb) of the skipjack tuna in the Hawaii fresh market at prices of $2.75–3.85 per kg ($1.25–1.75/lb). These predictions are almost exactly met by the number of vessels (6, 4 full-time), landings (955 t, 2.1 million lb), and average price ($2.87/kg, $1.30/lb) for skipjack tuna in 1991. Unless a larger market is developed, there is no reason to expect much expansion of Hawaii's skipjack tuna fishery in the near future. The pole-and-line fleet may continue to decline with age and the local market may increasingly be supplied by imports and by Hawaii's commercial troll fishery.

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Hawaii's Pelagic Fisheries

CHRISTOFER H. BOGGS and RUSSELL Y. ITO

Introduction

Hawaii's pelagic fisheries are small in comparison with other Pacific pelagic fisheries (NMFS, 1991), but they are the largest fisheries in the State (Pooley, 1993b), and much larger than other U.S. island-based fisheries in the western Pacific (Hamm et al.[1]). Stocks of tuna, billfish, and other tropical pelagic species supply most of the fish consumed by Hawaii residents and support popular recreational fisheries.

In recent years (1987–91) the composition and magnitude of Hawaii's commercial pelagic fisheries have changed. The longline fishery greatly expanded and the troll, handline, and pole-and- line fisheries declined (Ito[2]). The expansion of the longline fishery was consistent with fishery development plans that viewed pelagic fish resources as underexploited (State of Hawaii Division of Aquatic Resources (HDAR) 1985). Pelagic fish resources available to Hawaii fisheries may be capable of sustaining even greater yields. However, the decline of the troll and handline fisheries has raised concerns regarding the continued availability of pelagic species and local overfishing (Boggs[3], Ito[2]).

Pelagic fish availability is synonymous with local abundance, here defined as the amount of fish present within the range of the local fishery. Overall abundance refers to population size, which is greater than local abundance unless the entire population resides within range of the local fishery. The stock structure of large pelagic species is unclear, but a common assumption is that pelagic populations extend over much wider areas than are covered by Hawaii's fisheries (Skillman, 1989a, 1989b; Suzuki, 1989, In press; Miyabe, In press).

Availability probably depends on overall abundance, but the availability of fish to Hawaii's pelagic fisheries is also highly seasonal (Shomura, 1959; Yoshida, 1974; Skillman and Kamer[4]), suggesting that highly mobile pelagic fish change their distribution in response to environmental conditions (Seckel, 1972; Mendelssohn and Roy, 1986), or to enter different areas for reproduction. Availability may also be confounded with catchability, defined as the vulnerability of fish to being caught by a given type of fishing gear. Catchability is also influenced by environmental conditions (Sharp, 1978; Hanamoto, 1987).

The limited mobility of most island fishermen causes yield to be poor when availability is low. Intense local fishing effort is not likely to cause a decline in overall abundance unless there are discrete stocks residing in, or periodically returning to, island waters. Otherwise, the fishing mortality caused by Hawaii fisheries is minor compared with overall fishing mortality caused by larger Pacific fisheries. Thus, local fishing pressure is unlikely to cause a significant reduction in overall abundance.

Even though locally exploited pelagic stocks may be wide-ranging, and relatively invulnerable to local fishing pressure, catch per unit effort (CPUE) in local fisheries may decline if local fishing effort is so intense that most

[1]D. C. Hamm, R. S. Antonio, and M. M. C. Quach. 1992. Fishery statistics of the western Pacific. Vol. VII. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep H-92-06, var. pag.

[2]R. Y. Ito. 1992. Western Pacific pelagic fisheries in 1991. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-92-15, 38 p.

[3]C. H. Boggs. 1991. A preliminary examination of catch rates in Hawaii's troll and handline fisheries over a period of domestic longline fishery expansion. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin Rep. H-91-05, 62 p.

[4]R. A. Skillman and G. L. Kamer. 1992. A correlation analysis of Hawaii and foreign fishery statistics for billfishes, mahimahi, wahoo, and pelagic sharks, 1962–78. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-92-05, 44 p.

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ABSTRACT—Hawaii's diverse pelagic fisheries supply the bulk of the State's total catch. The largest Hawaii fishery is the recently expanded longline fishery, which now lands about 4,400 metric tons (t) of broadbill swordfish, Xiphias gladius; *1,500 t of bigeye tuna,* Thunnus obesus, *and 3,000 t of other pelagic species annually. The increased catch of these other species has raised concerns regarding the continued availability of yellowfin tuna,* T. albacares; *blue marlin,* Makaira mazara; *and mahimahi,* Coryphaena hippurus, *in the small-vessel troll and handline fisheries which target those species.*

Analysis of catch per unit effort (CPUE) statistics from Hawaii's fisheries did not provide strong evidence of recent declines in availability related to local fishery expansion. A more influential factor was variation in Pacific-wide CPUE, representing overall population abundance and catchability. Exogenous factors, including Pacific-wide fishing pressure, may overwhelm the influence of local fishing pressure on fish availability.

fish entering the local area are soon caught. It is hypothesized (Sathiendrakumar and Tisdell, 1987; Boggs, In press) that if fish availability depends on immigration, increases in local fishing effort result in an asymptotic yield, beyond which further increases in local effort do not increase the catch, and local CPUE declines. The possible impact of local fishing effort on the CPUE and profitability of Hawaii's pelagic fisheries is currently an issue of great concern to Hawaii's fishery managers (Boggs[3], In press).

This paper describes Hawaii's longline, troll, and handline fisheries for pelagic species, trends in landings and CPUE over time, and problems with the data used to monitor these fisheries. Changes in the apparent relative availability of fish (local CPUE) are reviewed in relation to local fishery expansion and overall abundance (Pacific-wide CPUE). Current attempts at managing for optimum yield and the outlook for these fisheries are described. The Hawaii skipjack tuna fishery is covered in a separate paper (Boggs and Kikkawa, 1993).

Synopsis of the Fisheries

The fishing methods, target species, vessel sizes, yields, and operational areas of Hawaii's domestic pelagic fisheries are diverse. The commercial sectors are largely composed of the pole-and-line and longline fisheries utilizing large (>12 m) vessels. The small-vessel troll and handline fisheries include poorly differentiated commercial, recreational, and subsistence components. The pole-and-line fishery targets skipjack tuna, *Katsuwonus pelamis*, and lands about 1,000 metric tons (t), (2.2 million lb) annually for sale to the local market (Boggs and Kikkawa, 1993). The longline fishery targets broadbill swordfish, *Xiphias gladius;* and bigeye tuna, *Thunnus obesus*, and now lands about 9,000 t (20 million lb, including all species) much of which is exported. The commercial, recreational, and subsistence troll and handline fleets primarily target yellowfin tuna, *T. albacares*; mahimahi, *Coryphaena hippurus*; and blue marlin, *Makaira mazara*; annual commercial landings (all species) now average about 2,300 t (5.2 million lb). No valid estimates exist for current recreational or subsistence landings (Pooley, 1993a).

Up until 1980 distant-water longliners from Japan caught between 1,300 and 5,000 t of tuna and billfish annually within the Exclusive Economic Zone (EEZ) around Hawaii (Yong and Wetherall, 1980) but since 1980 there has been no legal foreign longline fishing conducted in the EEZ. The Fishery Management Plan (FMP) enacted by the Western Pacific Regional Fishery Management Council (WPRFMC) was designed to regulate billfish catches by these foreign distant-water longliners (WPRFMC[5]). The Japanese distant-water pole-and-line fishery for skipjack tuna that operated in the Northwestern Hawaiian Islands (NWHI) through 1992 was the only foreign fishery operating legally within the EEZ after 1980 (Boggs and Kikkawa, 1993).

Although the primary target species of the domestic longline fishery are different from those of the troll and handline fisheries, the longline fishery also catches about 1,300 t (2.8 million lb) of yellowfin tuna, blue marlin, and mahimahi (combined). This creates a potential for fishery interaction between the longline and small-vessel troll and handline fisheries. Potential interactions, impacts on endangered species, the possibility of localized overfishing, and gear conflicts (Pooley, 1990) prompted the WPRFMC to establish regulations for the domestic longline fishery in 1990 (Dollar and Yoshimoto[6]). A moratorium on entry of longline vessels into the Hawaii fishery and prohibited areas for longline fishing were established in 1991.

[5]WPRFMC. 1986. Fisheries management plan for the pelagic fisheries of the western Pacific Region. Western Pacific Regional Fisheries Management Council (WPRFMC), Honolulu, HI 96813, 380 p.

[6]R. A. Dollar and S. S. Yoshimoto. 1991. The federally mandated longline fishing log collection system in the western Pacific. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-91-12, 35 p.

The Longline Fishery

Fishing Methods

Longline fishing gear consists of a main line strung horizontally across 1–100 km of ocean, supported at regular intervals by vertical float lines connected to surface floats. Descending from the main line are branch lines, each ending in a single, baited hook. The main line droops in a curve from one float line to the next and bears some number (2–25) of branch lines between floats. Fishing depth depends on 1) the lengths of the float lines and branch lines, 2) the sag in the main line, and 3) the position of the branch line, the deepest branch line positions being in the middle of the droop. Fishing depth affects the efficiency with which different species are captured (Hanamoto, 1976, 1987; Suzuki et al., 1977; Boggs, 1992).

One longline "set" is made per day of fishing, and for long main lines the deployment and retrieval may take almost 24 hours. Often the end of the line deployed first is retrieved last, so individual hooks may fish for a few hours, or all day (average ca. 12 hours). Traditionally the gear was set so that it fished primarily during daylight. For bait, Hawaii longliners used locally caught scad, *Decapterus* and *Selar* spp.; imported squid, *Loligo* sp.; sardines, *Sardinops caerulea*; herring, *Clupea pallasi*; and saury, *Cololabis saira*.

The Hawaii longline fishery began in 1917 off Waianae, Oahu, using techniques imported from Japan. Hawaii longline vessels evolved from the wooden sampan-style baitboats used in the pole-and-line fishery for skipjack tuna (June, 1950). The sampans used in the early years of the fishery (ca. 1950) were 12–19 m (40–63 ft) in length, high-bowed, and diesel-powered. They carried about 12 t of ice to chill an average catch of about 3 t (7,000 lb) of fish caught over an average trip of 10.5 days (June, 1950).

Old-style longlines were made of rope and composed of individual units called "baskets" named for the bamboo containers they were stowed in (June, 1950). Each basket was made

up of the float line, main line, and branch lines necessary for one segment of longline (one droop of the line). Poles with flags were attached to the floats to mark the gear, and longlining was generally referred to as "flagline" fishing.

Historical Development and Decline

Historically, the longline fishery was the second largest commercial fishery in the state after the pole-and-line fishery. By the 1930's longliners landed most of the 1,000 t (ca. 2 million lb) of yellowfin tuna, bigeye tuna, and albacore, *Thunnus alalunga*, landed in the Territory of Hawaii (June, 1950). After a hiatus during World War II the fishery quickly recovered, landing 900 t (2 million lb) of tuna, and 700 t (1.5 million lb) of billfish and other species in 1948. Landings continued to rise, reaching a record level of 2,000 t (4.4 million lb) in 1954 (Fig. 1A). The longline fishery declined in the late 1950's through the mid-1970's to reach a similar level of landings as the commercial troll (Fig. 2) and handline (Fig. 3) fisheries.

In the early years most of the catch was reported to have been in HDAR statistical areas 2–20 n.mi. (3.7–37 km) off Waianae, Oahu, and off Kona, Hilo, and Hamakua, Hawaii (June, 1950). Shomura (1959) reported greatly improved catch rates for bigeye tuna by longline vessels fishing off the windward coasts (i.e., Hilo) in winter as opposed to the traditional practice of fishing off sheltered leeward coasts (i.e., Waianae, Kona). Hida (1966) reported a growing number of longliners extending their range 100–400 n.mi. south of Oahu, and noted that CPUE was better than average in the southern area.

The species composition of longline landings changed over time. During 1951–64, more than 50% of longline landings (by weight) were bigeye tuna, also called ahi (a Hawaiian name), ahi mebachi, or "bluefin." True bluefin tuna, *Thunnus thynnus*, are rarely caught by Hawaii fishermen. Before 1950 and in the 1970's bigeye tuna and yellowfin tuna (also called ahi) made up roughly equal proportions of the catch (Fig. 1A). The proportion of blue marlin in the catch was higher than that of striped marlin, *Tetrapturus audax*, in the early 1950's but striped marlin became more predominant from the early 1960's to the present (Fig. 1A). Both marlin species are also called au (the Hawaiian name) or "swordfish," but they should not be confused with broadbill swordfish (Fig. 1B), which became the primary target species in the 1990's (Dollar[7]). Local common names for the pelagic species are often used for reporting catch statistics, resulting in some confusion.

The decline of the Hawaii longline fishery in the late 1950's through mid-1970's was characterized by a lack of new investment. Only a few new steel or fiberglass boats were built or added to the fleet between 1950 and 1982. Only 3 out of 11 boats surveyed in 1982 were built after 1970 (Hawaii Opinion[8]). Most longline vessels oper-

[7]R. A. Dollar. 1992. Annual report of the 1991 western Pacific longline fishery. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-92-11, 26 p.

[8]Hawaii Opinion, Inc. 1984. A cost earnings study of the longline and handline fishing fleets in Hawaii, a summary of the survey. Prepared for NMFS, 2570 Dole St., Honolulu, HI 96822–2396, contract number 81-ABC-00267, 113 p.

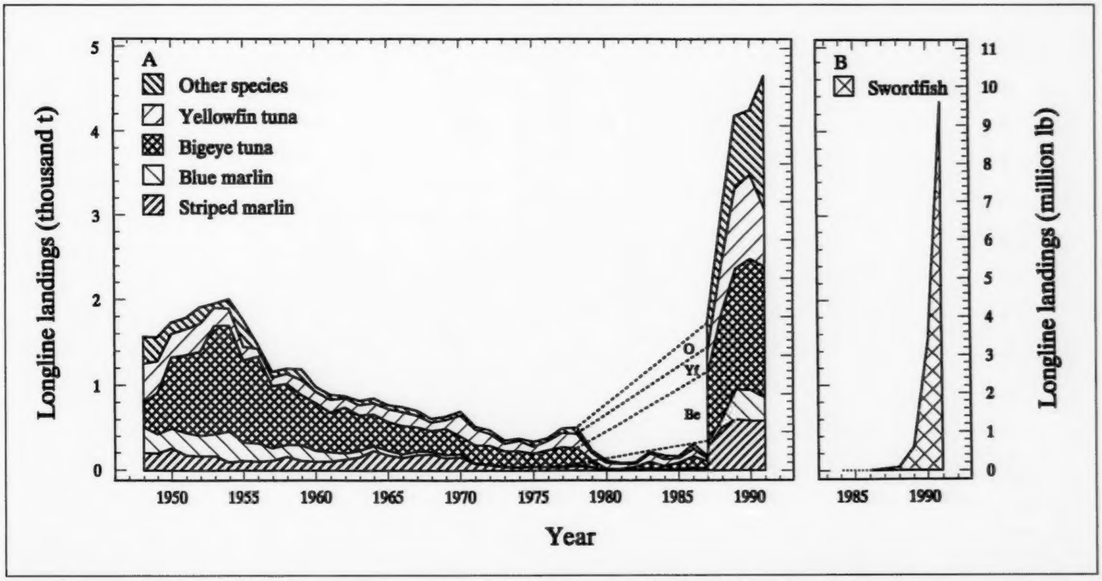

Figure 1.— Longline landings (in t and lb) in Hawaii from 1948–91, including A) component species except broadbill swordfish and B) broadbill swordfish. Total landings are the sum of stacked components. Dashed lines show corrected 1979–86 estimates for total landings, other species (O), yellowfin tuna (Yf), and bigeye tuna (Be). Sources: 1948–86, HDAR data; 1987– 91, NMFS estimates.

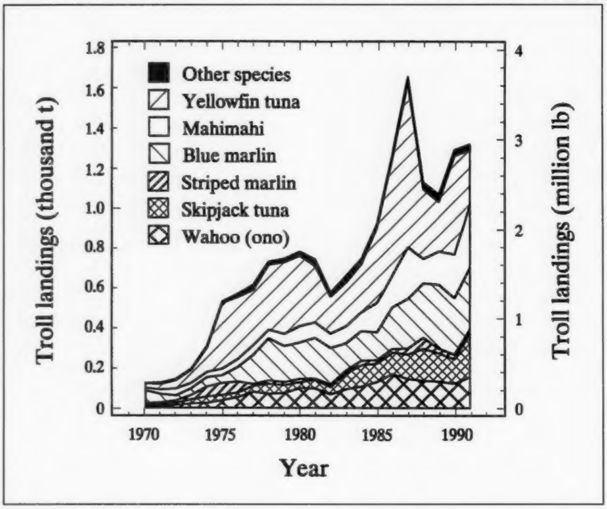

Figure 2.— Troll landings in metric tons (t) and pounds (lb) in Hawaii from 1970–91. Total landings are the sum of stacked components. Source: HDAR data.

ating through 1982 were veterans of the 1940's and 1950's. Low profitability probably contributed to the lack of investment in new vessels.

Local sale of fresh fish, mostly for raw consumption, provided a limited market that was easy to saturate, driving down the price (Otsu, 1954). The Hawaii fresh-fish market was the only outlet, because mainland U.S. consumers did not accept tuna as a fresh product. The Japan "sashimi" market was distant and exacted hard-to-meet product standards. Prices offered by tuna canneries were too low to provide adequate profits.

Although the number of vessels declined, the amount of fishing gear deployed in an average trip nearly doubled between the 1950's (Shomura, 1959) and the early 1980's (Hawaii Opinion[8]). The number of hooks per basket, and consequently the length of main line between float lines, also increased, resulting in a deeper gear configuration. A similar shift in gear configuration characterized the distant-water longline fleets of Japan and Korea (Suzuki et al., 1977; Yang and Gong, 1988).

The number of vessels participating in the Hawaii longline fishery over the years is difficult to document because many vessels fished part-time while participating in other Hawaii fisheries. June (1950) identified 49 vessels as primarily longliners (30 in Honolulu), whereas Hawaii Division of Aquatic Resources (HDAR) records indicate 76 registered longline vessels in 1950. Yoshida (1974) states that participation declined from 42 vessels in 1952 to 31 in 1964, and to 20 in 1970. Yuen[9] reported that the longline fleet in Honolulu numbered 15 in 1977, and by 1983 HDAR records showed only 13 registered longline vessels (10 in Honolulu).

The decline in vessels corresponded with the declining trend in longline landings reported to HDAR between 1954 and 1982 (Fig. 1A). However, visual inspection of the Honolulu fleet in 1983 found 37 vessels carrying longline gear (Honda[10]) as opposed to 10 registered with HDAR. Incomplete reporting to HDAR prompted the establishment of a NMFS market sampling program in late 1986 (Pooley, 1993b) and a Federal longline logbook program (Dollar and Yoshimoto[6]) was instituted by the WPRFMC in 1990 to collect more detailed data. A compari-

[9]H. S. H. Yuen. 1977. Overview of fisheries for the billfishes in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin Rep. H-77-19H, 14 p.

[10]V.A. Honda. 1985. An updated description of the Hawaiian tuna longline fishery. NMFS, 300 Ala Moana Blvd., Honolulu, HI 96850–4982, unpubl. manuscri.

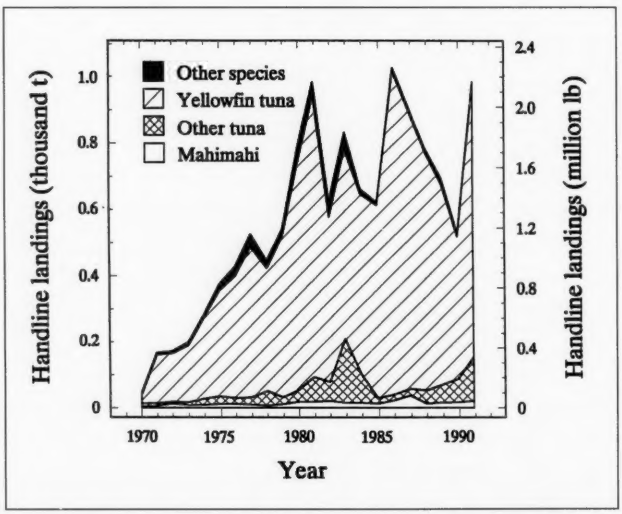

Figure 3.— Handline landings in metric tons (t) and pounds (lb) in Hawaii from 1970 to 1991. Total landings are the sum of stacked components. Source: HDAR data.

son between NMFS estimates of longline landings at wholesale markets and landings reported to HDAR in 1987 showed that less than 20% of longline landings were reported (Ito[2]).

The best available estimates of Hawaii longline landings over time (Fig. 1A) are based on three data sources and a correction to account for underreporting (Pooley, 1993b). HDAR longline data are believed to be relatively complete through 1978 (Pooley, 1993b). NMFS estimates based on market sampling and logbooks (Ito[2]; Pooley, 1993b) are used for 1987–91 (Fig. 1A and 1B). Estimates for 1979–86 (dashed lines, Fig. 1A) are interpolated values between HDAR reported landings in 1978 and NMFS estimates for 1987 (Pooley, 1993b). In contrast, HDAR troll (Fig. 2) and handline (Fig. 3) landings reported to HDAR through 1991 are very similar to NMFS estimates (Pooley, 1993b), and HDAR troll and handline data are used in this paper without correction. The corrected longline data indicate that the nadir of the longline fishery occured in 1975 (not 1982, Fig. 1A).

Revitalization and Expansion

The longline fishery expanded rapidly in the late 1980's to become the largest fishery in the state. The revitalization was due to the development of the local markets and export markets for fresh tuna on the U.S. mainland and in Japan (Kawamoto et al.[11]) and the introduction of new swordfish fishing methods in the late 1980's (Dollar[7]). Participation in the Hawaii longline fishery approximately doubled from 37 vessels in 1987 to 75 in 1989 (Ito[2]) and doubled again to 156 (vessels with permits) by the end of 1991 (Dollar and Yoshimoto[6]). Permits were required by the Federal moratorium on new entrants established in 1991. Only 140 of the vessels with permits were active in 1991. In 1988 landings data first exceeded the record set in 1954 (Fig. 1A) and by 1991 landings reached 9,000 t (20 million lb), including 4,400 t (9.6 million lb) of swordfish (Fig. 1B).

New entrants in the longline fishery were mostly steel-hulled vessels up to 33 m (107 ft) in length, and the majority of these vessels and their operators were former participants in U.S. east coast tuna and swordfish fisheries (Dollar[7]). The present fleet uses modern electronics (Radar, Loran, Global Positioning System (GPS)) to navigate, and uses radio beacons, strobe lights, and radar reflectors to mark the gear. Some vessels obtain sea-surface temperature maps by radio-facsimile (FAX) and most have electronic thermometers for use in finding fish associated with temperature fronts.

Changes in fishing methods and greater amounts of fishing gear characterized the expansion of the longline fleet. In 1988 most vessels still used basket-type, rope longline gear, but they deployed over 3 times as much gear on an average trip as vessels in 1982 (Hawaii Opinion[8], Kawamoto et al.[11]). A few vessels used "bin" gear in which the rope mainline is continuous, rather than composed of baskets, and these vessels deployed similar amounts of gear as those using basket gear (Kawamoto et al.[11]). Continuous nylon monofilament main lines stored on spools and used with snap-on monofilament branch lines were first used in 1985, and by the end of 1988, 29% of the fleet used this new system (Kawamoto et al.[11]). Monofilament gear was popular among new entrants to the Hawaii fishery and became the most prevalent gear type in the fleet. Longliners using monofilament gear tended to deploy over four times as much gear per trip in 1988 (Kawamoto et al.[11]) as was typical of the fleet in 1982 (Hawaii Opinion[8]).

Monofilament longline gear is more flexible in configuration and can be used to target various depths more easily than basket gear because the amount of main line, the number of branch lines, and the sag between floats are adjustable. This flexibility was demonstrated by the switch from traditional deep daytime fishing for bigeye tuna to shallow nighttime fishing, targeting broadbill swordfish in the 1990's (Ito[2]). Both daytime and nighttime methods are still practiced using the same monofilament longline system. In targeting bigeye tuna 12–25 hooks are deployed between floats with lots of sag to reach as deep as 400 m (Boggs, 1992), whereas in targeting swordfish only a few hooks are deployed between floats and the line is kept relatively taut so that it stays in the upper 30–90 m of water. Night fishing employs luminescent "light sticks" which attract broadbill swordfish and bigeye tuna or their prey (Berkley et al., 1981). Large imported squid, *Illex* sp., are used for bait.

A special "line thrower" is required to put sag into a monofilament longline as it is deployed (Kawamoto et al.[11]; Boggs, 1992) so that it can fish deeply for bigeye tuna. Many new entrants to the fishery in 1989–91 did not invest in line throwers. These vessels fished shallow even when targeting tuna (daytime fishing) and probably contributed to the increase in the relative proportions of yellowfin tuna, blue marlin, and other shallow-swimming species caught by longliners in recent years (Fig. 1A). The increasing longline catch of these species was cause for concern by the small-vessel troll and handline fisheries that target them (Boggs[3]).

The fishing grounds of the Hawaii longline fishery expanded in the 1980's and 1990's. Hawaii fishermen interviewed in 1982 reported that they had to fish farther away from port in order to make good catches (Hawaii Opinion[8]). In 1986 Hawaii longliners began exploring fishing grounds up to 800 n.mi. from the main Hawaiian Islands, and distant-water fishing is becoming more common in the 1990's. Logbook data from the first quarter of 1991 indicate that over half of longline sets were more than 50 n.mi. away from the main Hawaiian Islands, and <2% of sets were made outside the EEZ (NMFS[12]).

Conflicts with other fisheries and interactions with protected species led to the exclusion of the longline fishery

[11]K. E. Kawamoto, R. Y. Ito, R. P. Clarke, and A. E. Chun. 1989. Status of the tuna longline fishery in Hawaii, 1987–88. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-89-10, 34 p.

[12]NMFS Honolulu Laboratory, 2570 Dole St., Honolulu HI 96822-2396, unpubl. longline logbook data.

from nearshore waters in the 1990's. In early 1991 longline fishing was prohibited within a radius of 50 n.mi. off the NWHI (Dollar[7]) to prevent interactions between endangered Hawaiian monk seals, *Monachus schauinslandi*, and surface-fishing longliners that targeted aggregations of swordfish near those islands. In 1989 an informal agreement was negotiated between small-vessel fishermen and longline fishermen whereby longliners would keep >20 n.mi. from the coasts of the main Hawaiian Islands and >10 n.mi. from fish aggregating devices (FAD's). Some vessels, especially subsequent entrants to the fishery, did not comply with the agreement. To mitigate conflicts between longliners and small-vessel troll and handline fishermen, the WPRFMC in mid-1991 established a buffer zone prohibiting longline fishing within a radius of 75 n.mi. off the coasts of Kauai and Oahu, or within a radius of 50 n.mi. off the coasts of Maui, Molokai, Lanai, Kahoolawe, and Hawaii (Dollar and Yoshimoto[6]).

The Troll Fishery

Troll and handline fisheries in Hawaii have not been studied as extensively as the longline fishery. Trolling involves towing lures or baited hooks behind a moving vessel, whereas handlining involves dangling baited hooks from a stationary or drifting vessel. The evolution and operation of the Hawaii troll fishery are poorly documented. Trolling with lures for pelagic species was a traditional Polynesian fishing method, and Hawaii has since been the site of important innovations in big-game troll fishing techniques (Rizzuto, 1983).

The troll fishery has several components: 1) a recreational-subsistence sector which is poorly differentiated from a part-time commercial sector, 2) a charter sector which is recreational for its patrons but commercial for the operators who sell the catch, 3) a part-time commercial sector, and 4) a full-time commercial sector. Most troll vessels are small (5–8 m, 15–25 ft in length), although charter boats range up to 18 m (59 ft). In the mid-1980's large (20–26 m, 65–85 ft) troll vessels transiting the Hawaii EEZ to fish for albacore, *Thunnus alalunga*, in the North Pacific participated briefly in the Hawaii troll fishery, and vessels from the lobster and bottomfish fisheries also participate intermittently in the Hawaii troll fishery. Troll fishing is conducted throughout the Hawaiian islands, generally within 20 n.mi. of shore.

Commercial catch reports to HDAR do not distinguish between different types of troll fishing (i.e., part-time, charter); only fishermen who sell their catch are required to file reports. Reported annual commercial troll catches were <200 t (0.4 million lb) until 1974 (Fig. 2). During 1975–84 catches ranged between 540–790 t (1.2–1.7 million lb) per year, and then the catch rose to a record peak of almost 1,700 t in 1987. Annual catches declined after 1987 but remained >1,000 t (2.2 million lb) through 1991 (Fig. 2).

The troll fishery catches more mahimahi and wahoo, *Acanthocybium solandri*, than all the other Hawaii pelagic fisheries, about half the blue marlin, and about 20% of the yellowfin tuna landed. Yellowfin tuna composed almost half the commercial troll catch from 1975 to 1980, after which its proportion in the catch declined. The proportion of mahimahi and skipjack tuna in the troll catch increased through the 1980's and 1990's. The charter sector of the troll fishery targets blue marlin, and this species accounted for 54% and 39% of estimated charter catches in 1976 (Cooper and Adams[13]) and 1982 (Samples et al.[14]), respectively. In contrast, 87% of full-time commercial troll catches were yellowfin tuna (Cooper and Adams[13]). Changes in the relative size of the different commercial sectors (i.e., charter, part-time) may influence the species composition of the total reported catch (Fig. 2).

Charter vessels in the troll fishery numbered 102 and 119 in 1976 and 1982, respectively (Cooper and Adams[13]; Samples et al.[14]), compared to an estimated 160 full-time commercial, and 1,544 part-time and recreational-subsistence trollers (combined) in 1976 (Cooper and Adams[13]). Proportions of the total troll catch by these sectors in 1976 were 21% charter, 44% part-time commercial and recreational-subsistence (combined), and 35% full-time commercial. About 70% of the charter catch and 60% of the part-time commercial and recreational-subsistence catch was sold (Cooper and Adams[13]). Growth of the troll fishery makes it unlikely that these proportions represent the current situation but the charter fishery is believed to have grown with the expansion of tourism, and the recreational-subsistence fishery remains important (Pooley, 1993a).

The Handline Fishery

There are several types of pelagic handline fishing in Hawaii today. Day-handline fishing is a revitalization of an ancient Hawaiian method called "palu-ahi" for the use of "palu" (chum) to attract and hook ahi (yellowfin tuna). Palu-ahi fishing is also called "drop stone" fishing. A baited hook on the end of the handline is laid against a stone and the line wound around it. Additional pieces of chum are also wound into the bundle which is then tied in a slip knot (Rizzuto, 1983). The bundle is lowered to the preferred depth (commonly 20–30 m). Then the line is jerked to untie the knot so that the baited hook and chum are released.

Night-handline fishing is called "ika-shibi" from the Japanese names for squid (ika) and tuna (shibi). The ika-shibi fishery is an outgrowth of a squid fishery that probably began in the 1920's and did not target tuna until after World War II (Yuen, 1979). Ika-shibi fishermen attract squid to the fishing vessel with a light and catch the squid on jigs or with a gaff. The squid are then used as bait. Ika-shibi or palu-ahi were not distinguished as separate fishing methods in HDAR statistics

[13]J. C. Cooper and M. F. G. Adams. 1978. Preliminary estimates of catch, sales, and revenue of game fish for the fishing conservation zone around the main Hawaiian Islands, by types of troll and longline vessels and by species. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. 24H, 10 p.

[14]K. C. Samples, J. N. Kusakabe, and J. T. Sproul. 1984. A description and economic appraisal of charter boat fishing in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-84-6C, 130 p.

prior to 1982. Subsequently (1982–91) only a fraction of handline landings were reported as palu-ahi or ika-shibi, and so the handline catch statistics have been combined for this report (Fig. 3).

All handline catches were sold on the Island of Hawaii where the fishery was primarily located until 1971 when the rising price for tuna and reduced shipping costs made air shipment to Honolulu economically feasible. The increasing market for fresh fish boosted the development of Hawaii's fisheries in the mid-1970's (Pooley, 1993a). Annual commercial handline landings reported to HDAR increased from 45 t to almost 1,000 t between 1970 and 1981. Since 1981 commercial handline landings have ranged between 500 and 1,000 t (1.1–2.2 million pounds) with major peaks in 1981, 1983, 1986, and 1991 (Fig. 3). The magnitude of the recreational-subsistence sector of the handline fishery is unquantified, but important (Pooley, 1993a).

The composition of the handline catch is almost exclusively tuna; yellowfin tuna is the predominant species (Fig. 3). Mahimahi and other nontuna species make up less than 10% of the catch. Bigeye tuna are an important component of the handline catch (Yuen, 1979) that is not reflected in HDAR statistics. The ika-shibi catch of bigeye tuna ranged from 63 to 120 t (139–265 thousand lb) in 1973–75 (Yuen, 1979), but HDAR records indicate <23 t of tuna other than yellowfin landed by all handline fishing gears in 1973–75 (Fig. 3). This may represent a lack of reporting, but it is also likely that handline fishermen are lumping both bigeye and yellowfin catches as ahi in their catch reports since these species have the same Hawaiian name.

Most handline vessels are 6–9 m in length and are often crewed by 1–2 persons. Surveys by Yuen (1979) and Ikehara[15] indicate that the ika-shibi fishery grew from 30–40 boats in 1976 to at least 230 boats by 1980. In recent years some of the smaller longline vessels and larger commercial troll vessels have also done some handline fishing.

Day-handline fishing was concentrated around the Island of Hawaii and ika-shibi fishing was concentrated off the Hilo coast of Hawaii in the mid-1980's. Traditionally, handline fishing was conducted within a few km of the coast at locations called "ahi koas" where yellowfin and bigeye tuna were especially available. The State (HDAR) encouraged expansion into new areas in the late 1980's. Handline fishing techniques have spread and are now practiced on Kauai and Maui. Some of the largest handline vessels have extended their range to fish around seamounts and weather buoys 100–200 n.mi. from the coast. This new expansion of the fishery may have contributed substantially to the peak in catch reported in 1991, which followed four years of continuous decline (1987–90, Fig. 3). Some fishermen feel that there may soon be too many participants in the handline fishery, and the WPRFMC has been asked to institute a control date for this fishery in anticipation of possible limited-entry management.

The increasing cost of insurance has been a problem for small-vessel commercial fishermen. Many operators could not afford to keep up with rising insurance costs in the late 1980's and some, who weren't willing to risk their assets, stopped fishing. Another economic problem for the commercial troll and handline fisheries is a condition called burnt tuna syndrome (BTS) which discolors and gives a bad taste to sashimi as well as reduces its shelf life (Nakamura et al., 1987). BTS is prevalent in troll and handline-caught fish over 35 kg and uncommon in longline-caught fish. Proper handling can ameliorate BTS (Nakamura et al., 1987) and research is under way to find means to prevent it (Watson et al., 1988).

Abundance and Availability

Background

The primary concern in Hawaii's pelagic fisheries today is whether fishing effort should be limited to protect the local abundance or availability of fish (Pooley, 1990; Boggs[3], In press; Skillman et al., 1993). Increased catches by Hawaii's pelagic fisheries over the last two decades could hypothetically have reduced the abundance of local stocks, if such stocks exist. It is more likely that Hawaii's fisheries exploit locally available fractions of Pacific-wide stocks (Wetherall and Yong[16]; Skillman and Kamer[4]; Boggs, In press). In the latter case immigration may limit yields and excessive fishing effort might result in reduced CPUE (Sathiendrakumar and Tisdell, 1987; Boggs[3], In press). In either case, excessive local fishing pressure should be evidenced by corresponding declines in local CPUE.

Several studies suggest that local fishing pressure can reduce local CPUE for wide-ranging pelagic species (Wetherall and Yong[16], Squire and Au, 1990; Boggs[3], In press; Skillman and Kamer[4]). Many of these studies also found that the relative abundance (CPUE) of fish over a wider geographic area could statistically account for much of the variation in local CPUE. Relative abundance estimated as CPUE is confounded with catchability, so that widespread environmental effects on catchability, as well as true changes in stock-wide abundance, could explain the statistical relationships between Pacific-wide CPUE and local CPUE.

The following examination of Hawaii CPUE time series extending from the early years of each fishery to the present was undertaken to show whether or not the expansion of Hawaii's pelagic fisheries over the last two decades, 1970–91, corresponded with declines in local CPUE. Major declines in local CPUE were often found to predate local fisheries expansion and corresponded with declines in the CPUE of more widespread fisheries. Over the last few decades the time series indicated much interannual variation and little net change in CPUE.

[15]W. N. Ikehara. 1981. A survey of the ika-shibi fishery in the State of Hawaii, 1980. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-82-4C, 12 p.

[16]J. A. Wetherall and M. Y. Y. Yong. 1983. An analysis of some factors affecting the abundance of blue marlin in Hawaiian waters. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-83-16, 33 p.

Calculation of Hawaii CPUE

Longline CPUE was calculated from a combination of data sources including published literature, HDAR data summaries, and NMFS market sample estimates. Troll and handline CPUE was calculated solely from HDAR data summaries because these data identify troll and handline gears (NMFS estimates do not). HDAR summaries do not differ substantially (in total) from NMFS estimates for combined troll and handline (Pooley, 1993b). All available summary statistics (HDAR and NMFS) were used in the present study, but no new analyses of raw data were conducted.

To calculate CPUE in the early longline fishery (e.g., Fig. 4A), Hawaii longline data on two size-classes of vessels for 1948–56 (Shomura, 1959) were combined, and catch was converted from number of fish to weight. The results were similar to 1948–52 CPUE data published by Otsu (1954). The CPUE based on combined data differed little from the data for large vessels (Shomura, 1959), and although vessel size is important, it was ignored in the present study because data summaries by vessel size for subsequent years were not available.

Longline data summaries for 1959–89 and NMFS market sample longline estimates for 1987–89 (Ito[2]; Pooley, 1993b) were used to calculate longline CPUE for later years (e.g., Fig. 4A). HDAR longline data after 1978 are believed to represent only a fraction (ca. <20% Fig. 1A) of the fishery, but complete coverage is not required to calculate a representative CPUE index. No other data were available for 1979–86.

Two longline CPUE indices for 1987–89 were calculated, one from HDAR data, and another from NMFS estimates (e.g., Fig. 4A). The HDAR series from 1979 through 1989 best indicates the longline CPUE trend for those years, whereas the 1987–89 NMFS data best indicate recent CPUE for comparison with the earlier years 1947–78 (e.g., Fig. 4A). Longline CPUE was not calculated for 1990–91 because in these years a fraction of the longline fishery changed fishing methods to target broadbill swordfish, and additional work is needed to categorize the subset of the longline trips in 1990–91 that targeted tuna. The Hawaii swordfish fishery has developed too recently (Fig. 1B) for any trend in CPUE to be indicative of availability.

HDAR data summaries for the troll and handline fisheries from 1970 to 1991 were used to calculate CPUE time series for these fisheries (e.g., Fig. 4B). Prior data are not very important because the troll and handline fisheries were so small before 1970.

CPUE was calculated as the total annual longline, troll, or handline catch (by weight) of a species divided by total annual effort. Effort was estimated either as the annual number of fishing trips (troll and handline fisheries) or the annual number of hooks (longline fishery). Longline hook totals were calculated from the number of trips multiplied by estimates of hooks per trip (Boggs and Hawn[17]). Changes in the amount of gear deployed per trip obtained from descriptions of the fishery (June, 1950; Otsu, 1954; Shomura, 1959; Hida, 1966; Yoshida, 1974; Hawaii Opinion[8]; Kawamoto et al.[11]; Ito[2]) were used to estimate and interpolate the typical quantity of hooks per trip from 1947–89 (Boggs and Hawn[17]). Corrections for changes in efficiency with fishing depth are being developed (Boggs, 1992; Boggs and Hawn[17]) but are not used here.

The NMFS market sampling program counted fishing trips as each occasion that a vessel landed and sold its catch. HDAR data summaries included each unique date of landing for each unique license number in the records as a trip if any pelagic species were caught. Trip counts from both NMFS and HDAR data did not include trips with no catch of any pelagic species (prior to 1992). Such trips were seldom reported. For any given species the count of trips did include trips that did not catch that species but caught another pelagic species.

[17]C. H. Boggs and D. R. Hawn. Changes in fishing power and estimates of fishing effort for the Hawaii longline fishery, 1948–91. NMFS Honolulu Laboratory, 2570 Dole St., Honolulu HI 96822–2396, unpubl. manuscr.

The lack of data on the number of trips that caught no pelagic species may have caused errors in the effort estimates, but the CPUE time series based on those data may still be indicative of relative changes in availability. The number of zero-catch trips should have been negatively correlated with catch per successful trip (CPUE) since both were dependent on fish availability. Thus, the CPUE time series should still reflect real trends, especially if zero-catch trips represented a modest fraction of total effort. No bias was caused by changes in the fraction of zero-catch trips reported because none were counted. Uchida (1976) found a high correlation between Hawaii pole-and-line CPUE including zero-catch trips and CPUE excluding zero-catch trips.

The effort data for the troll and handline fisheries contained no standardization of trips as a unit of effort, and the longline effort data were standardized only to account for changes in the number of hooks per trip (Boggs and Hawn[17]). Changes in troll or handline fishing power, (number of lines, hooks, or hours, per trip, etc.) or changes in longline, troll, or handline efficiency (class of vessel, gear type, target depth, fishing strategy) may have resulted in biases in the CPUE time series, obscuring trends or giving the appearance of trends where none existed. Although much of the data presented here are decades old, the estimates of CPUE must be considered preliminary until the raw data are reanalyzed and effort standardized to account for changes in efficiency (e.g., Uchida, 1976; Suzuki, 1989).

Despite problems with the nonstandardized CPUE indices, they are the only data currently available. Nonstandardized Hawaii CPUE data for several different gear types often show a similar pattern (Skillman and Kamer[4]) or reflect a pattern similar to that of more sophisticated CPUE indices from nearby fisheries (Wetherall and Yong[16]). These examples suggest that some true information on relative availability is represented by nonstandardized CPUE indices for Hawaii's fisheries.

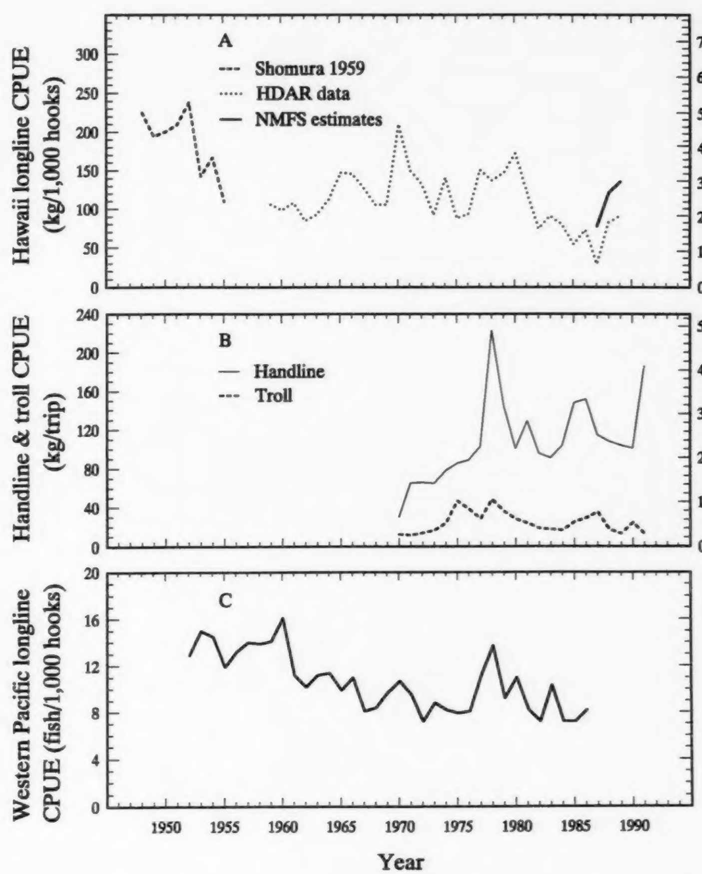

Figure 4.— Yellowfin tuna CPUE time series showing A) Hawaii longline CPUE (kg and lb per 1,000 hooks) from 1948–55 (Shomura, 1959), 1959–89 (HDAR data), and 1987–89 (NMFS estimates); B) Hawaii handline and troll CPUE (in kg and lb per trip) from 1970 to 1991 (HDAR data), and C) western Pacific longline CPUE (in no. fish per 1,000 hooks) in the Japanese fishery from 1952 to 1986 (Suzuki, In press).

CPUE Time Series

Yellowfin tuna CPUE in the Hawaii longline fishery declined between the 1950's and the early 1960's and then ranged between 90–210 kg/1,000 hooks with no clear trend from 1959–81 (Fig. 4A). Yellowfin tuna CPUE based on HDAR longline data declined from 1980–87, recovering somewhat in 1988–89. The more accurate longline CPUE index based on NMFS estimates indicated a return to average longline CPUE in 1988–89 (Fig. 4A).

The 1980–87 decline in yellowfin tuna CPUE for the Hawaii longline fishery occurred during a period of troll (Fig. 2) and longline (Fig. 1A) fishery expansion. However, the subsequent increase in longline CPUE in 1988–89 occurred during the period of greatest longline fishery expansion, while troll and handline fishing levels remained very high. Thus low levels of Hawaii longline CPUE did not correspond consistently with periods of higher fishing pressure.

Yellowfin CPUE in the Hawaii troll and handline fisheries (Fig. 4B) increased from 1970 to 1978 and subsequently declined through 1984. After 1984 Hawaii handline and troll CPUE increased to peaks in 1986 and 1987, respectively, and then declined (Fig. 4B). These declines coincided with expansion of Hawaii's longline, troll, and handline fisheries. However, handline CPUE subsequently increased from 1884 to 1986 and troll CPUE increased from 1984 to 1987 despite continued expansion of the troll and longline fisheries. During the period of greatest expansion of the longline fishery

(1987–89) troll and handline CPUE declined (Boggs[3]). However, troll CPUE returned to a typical level in 1990 and handline CPUE reached a high level in 1991 (Fig. 4B) despite continued high levels of fishing by all three pelagic fisheries. Thus availability (CPUE) of yellowfin tuna in Hawaii did not appear to be closely related to changes in local fishing pressure.

Local availability of yellowfin tuna seemed to follow patterns in the overall abundance or catchability of the stock as indicated by CPUE in wide-ranging Japanese longline and purse seine fisheries. Standardized yellowfin tuna CPUE in the longline fishery of Japan in the western Pacific from 1952 to 1986 (Suzuki, In press) indicated a drop in CPUE between the 1950's and early 1960's, and a decline in the early 1980's (Fig. 4C) similar to that seen in Hawaii longline CPUE data (Fig. 4A). In more recent years (1983–88), Hawaii troll CPUE followed a pattern that was similar to Japanese western Pacific purse-seine CPUE (Suzuki, In press; Boggs, In press; Skillman et al., 1993). Environmental anomalies affecting catchability may contribute much of the corresponding variation seen in CPUE time series, such as the peak in yellowfin tuna CPUE that occurred in 1978 (Fig. 4A and 4B).

An initial increase in bigeye tuna CPUE in the early years of the Hawaii fishery (Fig. 5A) was explained by Shomura (1959) as the result of a change in the area fished during winter as fishermen learned to target bigeye tuna. Set depth also changed between the late 1940's and early 1950's as the practice of buoying up the middle of each basket of gear with an extra float (June, 1950) was abandoned. Deep gear has been shown to be more efficient than shallow gear in catching bigeye tuna (Hanamoto, 1976; Suzuki et al., 1977; Boggs, 1992).

Bigeye tuna CPUE in the Hawaii longline fishery (Fig. 5A) and in the wide-ranging Japanese longline fishery (Fig. 5B) (Miyabe, In press) both showed downward trends from the late 1950's through the 1960's, a distinct drop in CPUE in 1970, a stable period in the mid-1970's, record low levels in 1980–81, and a slight recovery in the mid 1980's. The correspondence between the bigeye tuna CPUE statistics for the entire Pacific and for Hawaii is remarkable, and strongly suggests that local pelagic fish availability is linked to the abundance of a widespread population. An alternative hypothesis that could apply to all of the pelagic species is that CPUE variation is due to widespread changes in catchability associated with environmental trends.

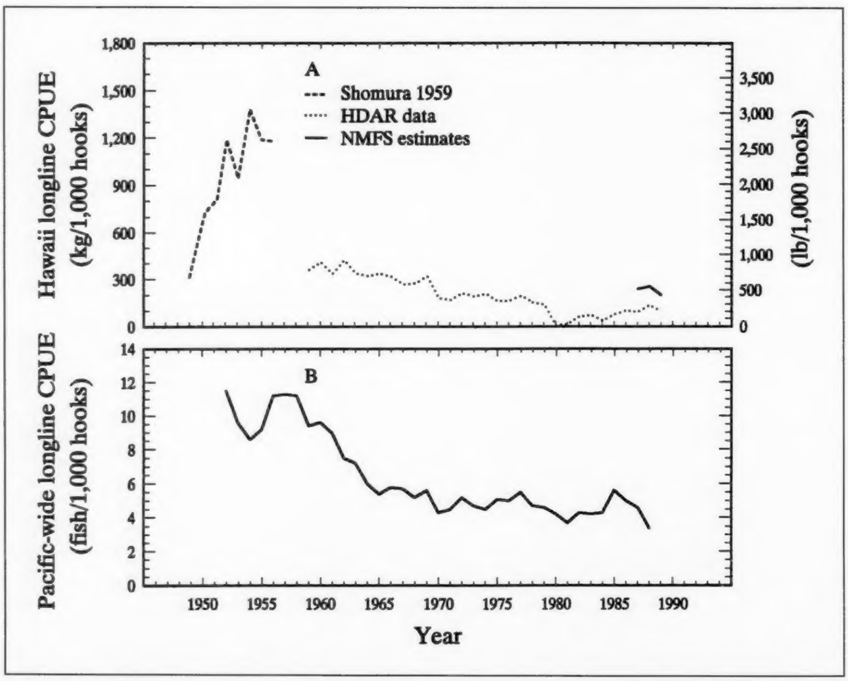

Figure 5.— Bigeye tuna CPUE time-series showing A) Hawaii longline CPUE (in kg and lb per 1,000 hooks) from 1949 to 1956 (fiscal years ending in June, Shomura, 1959), 1959–89 (HDAR data), and 1987–89 (NMFS estimates), and B) Pacific-wide longline CPUE (in no. fish per 1,000 hooks) in the Japanese fishery from 1952 to 1987 (Miyabe, In press).

For bigeye tuna, the Hawaii longline CPUE continued to recover in the late 1980's (Fig. 5A), whereas Japanese CPUE declined (Fig. 5B). The increasing trend in Hawaii bigeye tuna CPUE in the 1980's brought the CPUE index based on NMFS wholesale market sample back up to a level slightly higher than the average for 1970–78 (Fig. 5A) suggesting that local longline fishery expansion in the 1980's did not negatively affect bigeye tuna availability.

The blue marlin CPUE time series for the Hawaii longline fishery (Fig. 6A) showed peaks and minima for the same years as the Hawaii troll CPUE time series (Fig. 6B). The close correspondence between blue marlin CPUE in these two fisheries suggests that both CPUE time series reflected true changes in availability or catchability despite the limitations of the available statistics.

Blue marlin (Fig. 6A) and striped marlin (Fig. 7A) CPUE in the Hawaii longline fishery followed a pattern similar to Japanese longline CPUE data (Fig. 6C and 7B), as noted by Wetherall and Yong[16] and Skillman and Kamer[4]. This correspondence was not limited to the long-term decline in CPUE characteristic of longline fisheries in all oceans. Rather, for striped marlin both increases and decreases in CPUE in the Hawaii longline fishery (Fig. 7A) corresponded with CPUE changes in the North Pacific Japanese longline fishery (Fig. 7B).

The sharp increase in longline CPUE for blue and striped marlin in 1989 probably reflected the increased use of monofilament longline gear without

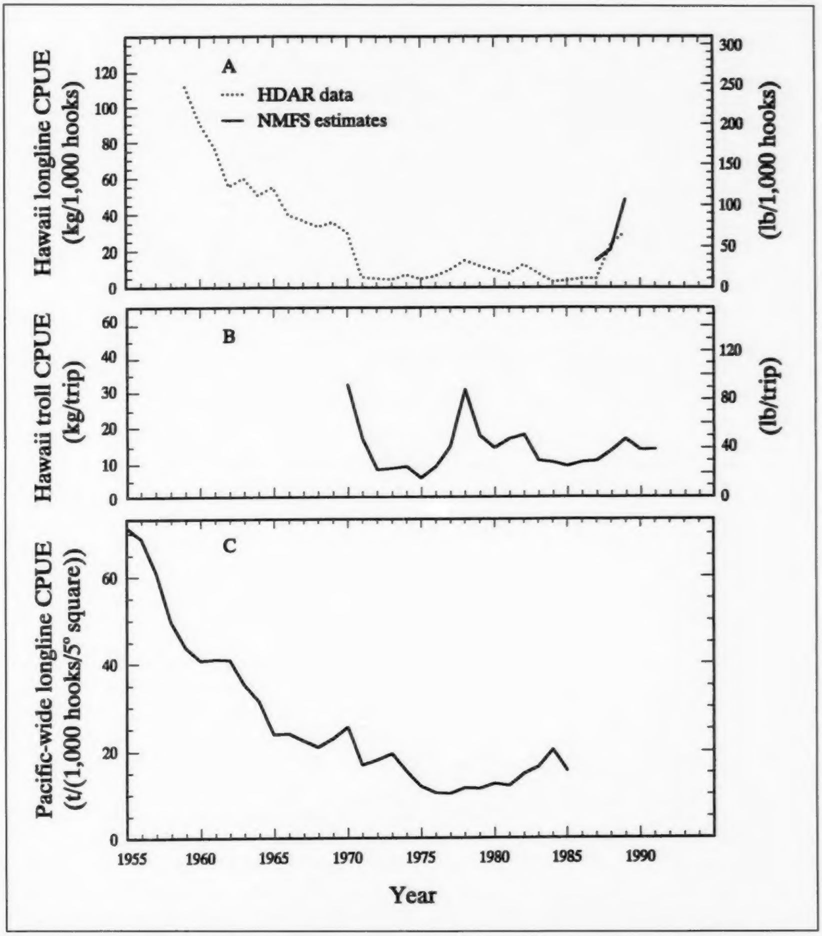

Figure 6.— Blue marlin CPUE time-series showing A) Hawaii longline CPUE (kg and lb per 1,000 hooks) from 1959 to 1989 (HDAR data), and 1987–89 (NMFS estimates), B) Hawaii troll CPUE (in kg and lb per trip) from 1970 to 1991 (HDAR data), and C) Pacific-wide longline CPUE (in t per 1,000 hooks per 5° square) in the Japanese fishery from 1955 to 1985 (Suzuki, 1989).

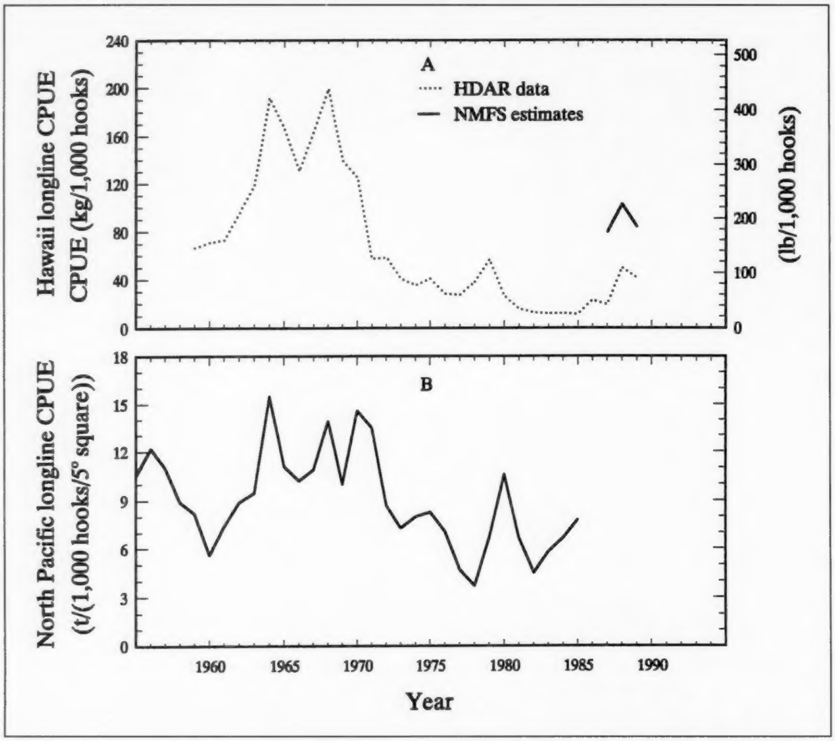

Figure 7.— Striped marlin CPUE time series showing A) Hawaii longline CPUE (in kg and lb per 1,000 hooks) from 1959 to 1989 (HDAR data), and 1987–89 (NMFS estimates), and B) North Pacific longline CPUE (in t per 1,000 hooks per 5° square) in the Japanese fishery from 1955 to 1985 (Suzuki, 1989).

line-throwers, which resulted in shallower sets and increased the efficiency of the gear for marlin (Suzuki, 1989; Boggs, 1992). Blue marlin CPUE in the troll fishery appears to be at a normal level and relatively stable (Fig. 6B) despite the expansion of Hawaii's pelagic fisheries.

Mahimahi CPUE in the Hawaii longline fishery (Fig. 8A) reached a peak in 1972 and a minimum in 1988 that were mirrored in the Hawaii troll and handline CPUE data (Fig. 8B). Troll and handline CPUE data corresponded with each other very closely. Mahimahi CPUE appears to be increasing in both the troll and handline fisheries.

Outlook for the Pelagic Fisheries

The absence of clear declining trends in local CPUE associated with local fishery expansion, combined with distinctly seasonal variations in CPUE (Shomura, 1959; Yoshida, 1974; Skillman and Kamer[4]), suggests that pelagic fish availability in Hawaii was most strongly affected by factors other than local fishing pressure. Anomalies in whatever factors control seasonal availability could also be the major source of interannual variation in CPUE. Research leading to an ability to forecast changes in pelagic fish availability could ameliorate fishermen's concerns that local fishing pressure has decreased fish availability. Development of new methods to locate or predict productive fishing areas could increase the yield and efficiency of Hawaii's pelagic fisheries. However, greatly increased fishing efficiency and yield might then have some negative impact on local fish availability.

Decreases in fish availability caused by local fishing pressure may have been obscured by biases such as increased fishing power, expansion into more productive fishing grounds, economic influences on fishing operations, and environmental influences on local abundance and catchability. Further analysis of catch and effort data as well as an improved data collection system are needed to attempt to account for such biases. However, the parsimonious explanation of the available data is that locally exploited stocks have not yet been impacted by the expansion of Hawaii's pelagic fisheries.

Long-term declines in the overall apparent abundance of many pelagic species occurred several decades ago (Figs. 4C, 5C, and 6C), before the latest (1970–91) expansion of Hawaii's pelagic fisheries. Pacific-wide declines in CPUE do seem to affect Hawaii's fisheries, and could reflect full exploitation or even overexploitation of the stocks. However, reduction of local

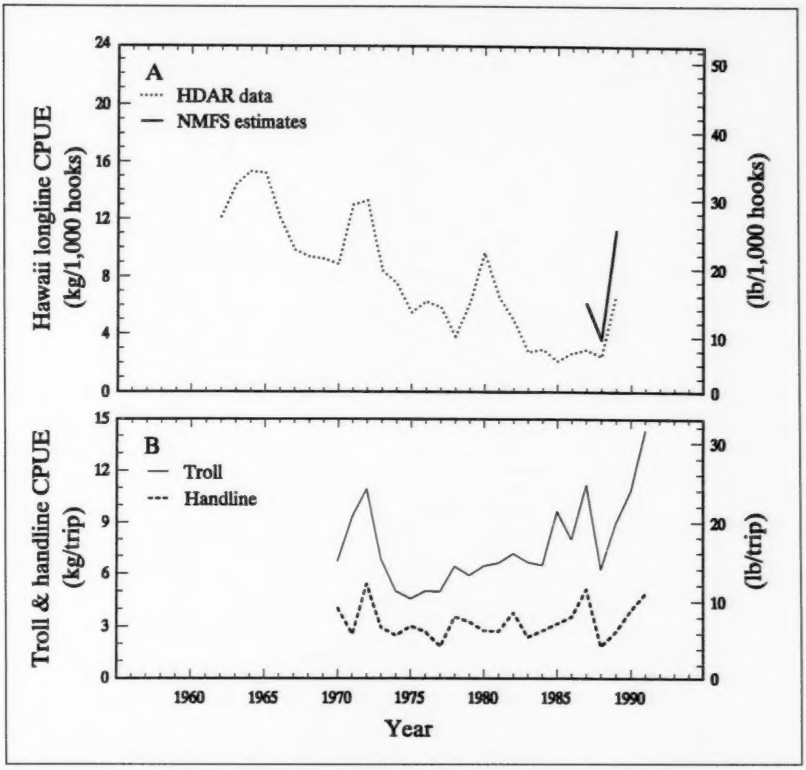

Figure 8.— Mahimahi CPUE time series showing (A) Hawaii longline CPUE (kg and lb per 1,000 hooks) from 1962 to 1989 (HDAR data), and 1987–89 (NMFS estimates), and (B) Hawaii troll and handline CPUE (in kg and lb per trip) from 1970 to 1991 (HDAR data).

fishing effort from current levels would not substantially affect stock-wide abundance because of the relatively small scale of Hawaii's pelagic fisheries. An exception might be the nighttime longline fishery for broadbill swordfish, which has been operating for too short a time to evaluate. However, with annual landings of 4,400 t and continued growth, the Hawaii swordfish fishery may be expected to contribute significantly to total fishing mortality on the stock. Historically, maximum total Pacific yields of swordfish have been on the order of 20,000 t per year (Bartoo and Coan, 1989).

If fishery managers can prevent physical conflicts between the longline and small-vessel troll and handline fisheries in Hawaii (Pooley, 1990; Skillman et al., 1993), and if adequate markets continue to support the profitable operation of all fishery sectors, then Hawaii's pelagic fisheries should continue to expand. No strong evidence suggests that the local availability of fish is a factor limiting further expansion. However, this optimistic assessment is based on statistics and analyses that may be inadequate; therefore, better fishery monitoring systems are needed.

Acknowledgments

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A Review of Interactions Between Hawaii's Fisheries and Protected Species

EUGENE T. NITTA and JOHN R. HENDERSON

Introduction

Interactions involving commercial fisheries and small odontocetes protected by Federal statutes have occurred in Hawaii since 1948 (Schlais, 1984, 1985), and reports from fishermen about small cetaceans stealing catch and bait continue to surface periodically throughout the Hawaiian Islands. Several species of sea turtles and whales are also involved in fisheries through entanglement or accidental hooking. The threatened and endangered species involved in fishery interactions are the Hawaiian monk seal, *Monachus schauinslandi*; humpback whale, *Megaptera novaeangliae*; leatherback turtle, *Dermochelys coriacea*; olive ridley turtle, *Lepidochelys olivacea*; loggerhead turtle, *Caretta caretta*; hawksbill turtle, *Eretmochelys imbricata*; and green sea turtle, *Chelonia mydas*. Nonendangered marine mammals identified as interacting with commercial fisheries in Hawaiian waters include bottlenose dolphins, *Tursiops truncatus*; false killer whales, *Pseudorca crassidens*; rough-toothed dolphins, *Steno bredanensis*; and spinner dolphins, *Stenella longirostris*. Among seabirds, which are protected by the Migratory Bird Treaty Act of 1918, albatrosses, *Diomedea* sp.; and boobies, *Sula* sp., are reported involved in fishery interactions.

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ABSTRACT—Several fisheries in Hawaii are known to have interactions with protected cetaceans, seabirds, marine turtles, or seals. Handline fisheries for bottomfish, tuna, and mackerel scad lose bait and catch to bottlenose dolphins, rough-toothed dolphins, and Hawaiian monk seals. Troll fisheries for billfish lose live bait to bottlenose dolphins, rough-toothed dolphins, albatrosses, and boobies; these fisheries may also lose catch to false killer whales. A longline fishery for tuna and billfish has burgeoned in Hawaii since 1987, resulting in interactions with protected species; marine turtles, seabirds, and monk seals take bait and are known to become hooked, and false killer whales may take catch. Research on deterrents or alternative fishing methods has been limited, and interactions have been reduced primarily through management and regulatory actions. These include area closures and gear requirements. An observer program has also been established for the bottomfish and longline fisheries.

This paper describes protected species interactions with Hawaiian commercial fisheries on a fishery by fishery basis. Hawaiian commercial fisheries will include the areas fished by the distant water fleets originating from Hawaii even if outside of the 200-mile Exclusive Economic Zone (EEZ) surrounding the Hawaiian Archipelago. Efforts to document and resolve protected species/fishery interactions will also be described.

Biology and Status of Protected Species

Small Cetaceans

Four species of small cetaceans interact with fisheries in Hawaii, but three (bottlenose dolphin, rough-toothed dolphin, and false killer whale) occur pelagically as well as within the Archipelago. Animals which are sighted inshore and interact with fisheries may mix with their pelagic conspecifics, but the extent of such movement is not known.

The bottlenose dolphin is found throughout the Hawaiian Archipelago, usually within five miles of emergent land or shallow banks (Shallenberger, 1981). School sizes range from single or small groups of 3–10 animals to aggregations of more than 100 (Tomich, 1986). A combined aerial and vessel survey of inshore waters adjacent to Oahu, Molokai, Lanai, Maui, and Hawaii documented a minimum of 430 individuals[1].

The rough-toothed dolphin is found near all major islands within the Archipelago (Tomich, 1986), and at least as far north as French Frigate Shoals (JRH, personal observ.). No estimates of abundance exist. At least 23 were collected from Hawaiian waters for oceanaria in 1963–81 (Shallenberger, 1981).

The false killer whale is found near all the main islands, but its occurrence and distribution in the Northwestern Hawaiian Islands (NWHI) is unknown. An aerial survey of the lee areas of Oahu, Lanai, and Hawaii documented a minimum of 470 individuals, all of which were sighted along the northwestern coast of Hawaii[2].

Spinner dolphins occur in relatively discrete schools frequenting inshore bays and lagoons within the Archi-

[1]Naval Ocean Systems Center, Kaneohe Marine Corps Air Station, Kaneohe, HI. 1987. Unpubl. aerial survey data.

[2]S. Leatherwood and R. R. Reeves. Aerial survey for false killer whales off Hawaii, June 1989. 2146 Fort Stockton Dr., San Diego, CA 92103. Unpubl. rep., 13 p.

pelago, from the island of Hawaii to Kure Atoll. The largest school (200 – 250 animals) occurs along the west coast of Hawaii from Honokohau Harbor to Kiholo Bay (Norris and Dohl, 1980). Schools disperse to deep water at night to feed and return inshore to rest during the day. Some mixing of animals between schools may occur during feeding forays.

Humpback Whale

Humpback whales that winter in Hawaii are part of the North Pacific population, estimated at 1,200 – 2,000 animals (Johnson and Wolman, 1984; Darling and Morowitz, 1986; Baker and Herman, 1987). The Hawaiian stock is estimated at 1,407 ± 294 (95% confidence limits) whales (Baker and Herman, 1987). These whales begin arriving from North Pacific summer feeding grounds in December. The number of whales peaks in late January through February. In April, they begin migrating out of Hawaiian waters, and by late May or early June the last whales usually have departed. A few animals have been sighted in the NWHI[3].

Hawaiian Monk Seal

The only seal native to the Hawaiian Islands, the Hawaiian monk seal, is found around all of the NWHI and is occasionally seen in the main islands. The major pupping islands are in the NWHI. The total population for the five major breeding locations plus Necker Island in 1987 was estimated to be 1,718 seals[4] including 202 pups of the year (Gilmartin[5]). Significant declines in pupping and juvenile survival, particularly at French Frigate Shoals since 1989, are cause for concern for this endangered species.

Sea Turtles

Five species of sea turtle interact with fisheries in Hawaii, but only one, the green sea turtle, nests in large numbers in the Archipelago and represents a distinct population. There are isolated nesting sites for hawksbill turtles in the main Hawaiian Islands, primarily on the islands of Hawaii and Molokai. The remaining three species nest elsewhere in the Pacific Basin.

Leatherback turtles are commonly seen by fishermen in Hawaiian offshore waters, generally beyond the 100 –fathom contour but within sight of land. Sightings often occur off the north coast of Oahu and the west coast of Hawaii. The pelagic zone surrounding the Hawaiian Islands likely constitutes foraging habitat and migratory pathways for this species. A high-seas aggregation of leatherbacks is known to occur north of the Hawaiian Islands at lat. 35°– 45°N, long. 175°– 180°W (Balazs et al.[6]; Skillman and Balazs, 1992). The nesting habitat and origin of these turtles are not known.

Available information suggests that the olive ridley turtle regularly uses the Hawaiian pelagic region for foraging and/or developmental migrations. Olive ridleys in reasonably good health have been found entangled in scraps of net or other floating synthetic debris. Small crabs, barnacles, and other marine life often reside on the debris and likely serve as food attractant to turtles. Juvenile and subadult olive ridleys are among the life stages known to be present in Hawaiian waters. Olive ridleys found in Hawaiian waters are probably derived from the eastern Pacific breeding aggregation of Mexico (Balazs et al.[6]).

The loggerhead turtle is a cosmopolitan species found in temperate and subtropical waters. Nearly all nesting occurs north of 25°N or south of 25° S. Adult loggerheads undertake long reproductive migrations between their nesting sites and foraging areas. However, their dispersal patterns in foraging areas are not well known for any population. In the North Pacific the only major nesting beaches are in the southern part of Japan (Dodd, 1988). Although reliable counts are not available, as many as 2,000 –3,000 loggerheads may nest annually on beaches throughout Japan. Immature loggerheads encountered during driftnet fishing in the North Pacific may originate from nesting beaches in Japan, being transported to the north and east by the Kuroshio Current and its extension (Wetherall et al., In press). Loggerheads reported taken in the Hawaiian longline broadbill swordfish fishery may be of the same origin.

The green sea turtle is found throughout the Hawaiian Archipelago. Its distribution, however, has been reduced in recent historical times; breeding aggregations have been eliminated, and certain foraging areas are no longer used in the main Hawaiian Islands (Balazs, 1980; Balazs, et al., 1987). More than 90 percent of the breeding and nesting activity of Hawaiian green turtles occurs at French Frigate Shoals, in the NWHI. The number of females nesting there fluctuates annually. An annual mean as high as 300 was recorded during 1973–1982. The total mature female population at French Frigate Shoals is estimated to be approximately 750 animals (Balazs et al.[6]).

Seabirds

All five species of seabirds known to interact with fisheries nest on remote islands throughout the Archipelago. Recent estimates of abundance in Hawaii are 683,500 breeding pairs for the two albatross species[7], and 6,590–7,950 breeding pairs for the three species of booby (Harrison et al., 1984).

Fishery Interactions

Interactions between cetaceans and fisheries have been documented in Hawaii since at least the late 1940's and

[3]M. Craig, Southwest Fisheries Science Center, Honolulu Laboratory, 2570 Dole St., Honolulu, HI 96822–2396. Personal commun. 1993.

[4]This estimate utilizes counts of adult males at Lisianski made during the late summer molting season, which confounds the total estimate somewhat because beach counts at the other islands were conducted in the spring.

[5]W. G. Gilmartin. 1988. The Hawaiian monk seal: Population status and current research activities. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab.,. Southwest Fish. Cent. Admin. Rep. H-88-17, 14 p.

[6]G. H. Balazs, H. F. Hirth, P. Y. Kawamoto, E. T. Nitta, L. H. Ogren, R. C. Wass, and J. A. Wetherall. 1992. Interim recovery plan for Hawaiian sea turtles. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-92-01, 76 p.

[7]E. Flint, U.S. Fish and Wildlife Service, Pacific/Remote Islands NWR Complex, P.O. Box 50167, Honolulu, HI 96850. Personal commun. 1993.

were exacerbated by installation in 1979 of a deep-water buoy as part of the Ocean Thermal Energy Conversion (OTEC) project west of the island of Hawaii (Schlais, 1984, 1985). This buoy proved very productive as a fish aggregating device, was popular with fisherman from Kona, and became well known for schools of dolphins stealing bait and catch. Interactions further increased in the early 1980's with the deployment of fish aggregation devices (FAD's) by the Hawaii Division of Aquatic Resources throughout state waters. Specific fisheries and the species involved have been documented by Mate (1980), Shallenberger (1981), and Kuljis[8].

Interactions may be divided into two basic types in this region. One involves the loss of catch or bait with little or no impact to the individual animals from the fishing gear or technique, short of aversive action taken by the fishermen. The other is the hooking or entanglement of animals in gear whether or not catch or bait is the primary stimulus for interactions. While documenting these two types of interactions is relatively straightforward, investigating how these take place, assessing the impact on fisheries and protected species, and developing solutions to incidental take and loss of catch are much more difficult.

Loss of catch is documented through observer reports, interviews with fishermen, and reports directly from fishermen through fish catch/interaction logs. Entanglements and hookings are reported in the same manner.

Handline Fishery for Bottomfish

Boats in this fishery use 3–6 lines, each with 6–15 hooks, usually baited with squid. Hooks are spaced in approximately 0.5 m intervals and are fished at depths of 120–250 m. A chum bag containing chopped fish or squid may be suspended above the highest of these hooks. The gear is pulled after several fish are hooked. Locations for this fishery include the main islands as well as banks in the NWHI.

Both bait and catch have been reported lost to bottlenose dolphins, and schools of dolphins have been reported following fishing boats, particularly in the NWHI. Danger to fishermen results when a dolphin jerks a fish from a hook; the dolphin may pull 10–15 m of line from the fisherman's hands, exposing the fisherman to the risk of open hooks. Interactions with dolphins have been reported off the island of Hawaii, Kaula Island, and several banks in the NWHI. Dolphins may be attracted by undersized fish or unmarketable species (e.g., kahala, *Seriola dumerili*) which are discarded during fishing operations. In some cases after consuming a few fish the dolphins will continue to remove fish from the lines and "play" with them.

Interactions between Hawaiian monk seals and the bottomfish fishery have occurred in the main Hawaiian Islands and the NWHI. A female Hawaiian monk seal was observed with an "ulua" hook in its mouth on Kauai in October 1989. The hook was removed from the seal with no apparent serious aftereffects[9]. A Hawaiian monk seal was photographed at French Frigate Shoals with a bottomfish hook in its mouth in 1982. The seal was later observed alive without the hook (Henderson, 1985). Like dolphins, monk seals may be attracted by discarded bycatch (Fig. 1).

Reports of monk seals and bottlenose dolphins taking bottomfish off fishing lines from around Necker Island and Kaula Island were received from commercial fishermen in 1983–1987[10]. In 1991 and 1992 observer trip reports from the bottomfish fishery documented monk seals and bottlenose dolphins taking fish off of lines in the NWHI. A rate of one interaction event/34.4 hours of fishing was calculated for monk seals and a rate of one interaction event/24.3 hours for bottlenose dolphins based on observer reports through July 1992[11].

Day Handline Fishery (Palu-ahi) for Tuna

Boats in this fishery use 3–5 lines, each with a single hook, baited with mackerel, mackerel scad, or squid, and fished at a depth of up to 150 m. The fishery targets both skipjack and yellowfin tuna. The location for this fishery is primarily off the southeast and west coasts of the island of Hawaii, often in association with FAD's in other areas of the main Hawaiian Islands as well. Bottlenose dolphin and rough-toothed dolphin take both bait and catch.

Night Handline Fishery (Ika-shibi) for Tuna

Bigeye tuna and yellowfin tuna are taken in this night handline fishery at the edge of the island shelf near the 1,000 fathom contour from 2 to 20 km from shore. This fishery occurs predominantly south of the island of Hawaii from Hilo to around Captain Cook, but also occurs around FAD's throughout the main islands. The boats use 20–30 watt bulbs underwater or over the surface to attract squid, *Stenoteuthis oualeniensis* which is caught for bait or market. Other baits include frozen mackerel or squid. The bait is typically fished at 30 m depth. Loss of catch and bait as well as poor catch rates have been attributed to bottlenose dolphins. Poor catch has also been attributed to sharks.

Handline Fishery for Mackerel Scad

This fishery takes place at night, primarily off the west shores of Oahu and the island of Hawaii. Lights are used to illuminate an area around the boat, and a line with several hooks, either

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[8]B.A. Kuljis. 1983. Porpoise/fisheries interactions within the Hawaiian Islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-88-19C, 16 p.

[9]W. Gilmartin. Southwest Fisheries Science Center, Honolulu Laboratory, 2570 Dole St., Honolulu, HI 96822-2396. Personal commun. 1993.

[10]E. W. Shallenberger. 1983. 1440 Woodland Ave., Anacortes, WA 98221. Unpublished report to the Marine Mammal Commission and personal commun. 1991.

[11]J. K. Hale and C. W. Coon. 1993. Summary report - Bottomfish observer trips in the Northwestern Hawaiian Islands, October 1990 to June 1992. Pacific Area Office, Southwest Region, 2570 Dole St., Honolulu, HI 96822–2396. Unpubl. rep.

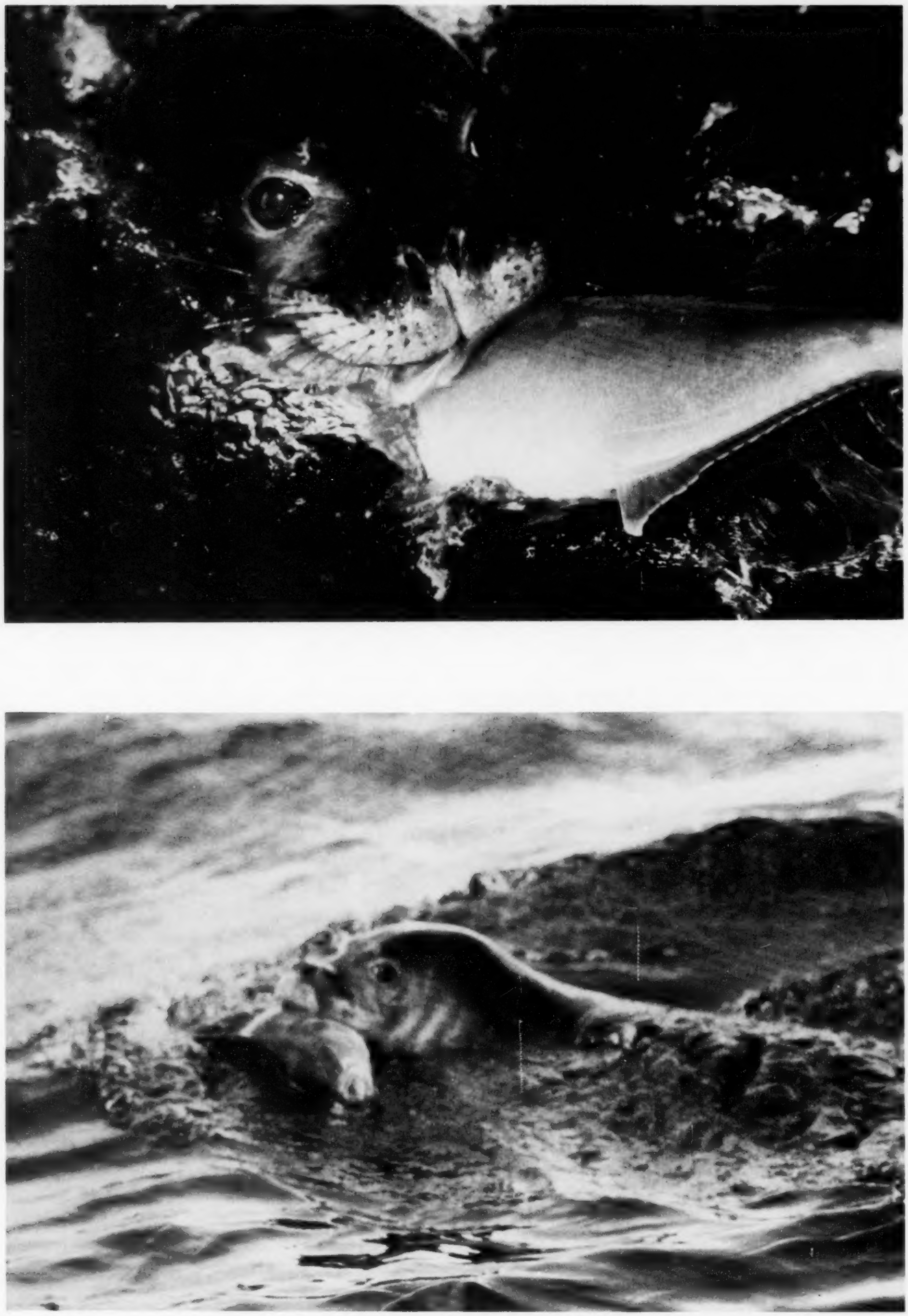

Figure 1.—Hawaiian monk seal consuming a discarded kahala (photo by Frank LaSorte, NMFS).

baited or with feathered jigs, is fished at 15–25 m. Bottlenose dolphin have been observed taking catch, but not bait or lures. Fishermen may be snagged by open hooks when dolphins take the catch and run with it.

Trolling for Billfish and Tuna

This fishery is a sport and commercial fishery located in waters near Honolulu and along the Kona (west) coast of the Island of Hawaii. Gear involves trolling lures or live bait near the surface. Catches of both billfish (marlin and spearfish) and tuna have been reported taken by false killer whales (Zimmerman, 1983). One fisherman reported a false killer whale surfacing immediately astern of his boat holding the catch (a marlin) crosswise in its jaws (Zimmerman, 1983). Catch may either be damaged or removed from the hook entirely. Rough-toothed dolphins, bottlenose dolphins, albatrosses, and boobies have also been observed taking live bait.

Longline Fishing for Tuna and Billfish

The Hawaiian longline fishery for broadbill swordfish has developed rapidly since 1987 when fewer than 40 vessels were in the fleet, landing less than 30,000 pounds of broadbill swordfish, a bycatch product of the tuna longline fishery. As of September 1992, the Hawaiian longline fishing fleet comprised about 165 vessels with permits, of which approximately 100 were active. Up to 40 of these vessels have been recorded as targeting broadbill swordfish in the NWHI.

The major fishing grounds for broadbills in the central Pacific region, traditionally exploited by foreign longliners, lie approximately 1,000 miles north of the Hawaiian Islands (25°–40°N.). Local longliners have fished closer to the islands, especially off the NWHI around "66 Fathom Bank" near French Frigate Shoals, St. Rogatien and Brooks Banks, and Gardner Pinnacles. A typical set consists of 16–48 km of monofilament line having as many as 700–1,000 branch (leader) lines and an equal number of hooks. The leader line is relatively short, 9–18 m long, to which is attached a "night lightstick" (a luminescent lure) about 76 cm above a broad, flat hook (8/0–9/0 Mustad). Whole squid is the preferred bait for catching broadbills. The longline is set in the evening and retrieved early the next morning.

Midwater longlines are used to catch bigeye and yellowfin tuna in the tuna longline fishery. A main line is suspended from buoys, and dropper lines are attached to the main line. Hooks are baited with whole fish of several species. Lines are usually deployed from vessels larger than 15 m. Main lines are frequently more than 32 km long with 1,000–1,400 hooks. Although yellowfin and bigeye tuna are the targeted species, swordfish, albacore, sailfish, marlin, shortbill spearfish, and sharks are often caught.

Until recently, interactions between monk seals and the longline fishery were not believed to constitute a problem in the NWHI. Events in 1990 and 1991 indicated that monk seal interactions were occurring at a level and in a manner not previously considered. Seven injured seals were observed during a survey of monk seals and turtles at French Frigate Shoals in May 1990[12]. All had head injuries ranging from abrasions to gaping wounds which could not be attributed to shark attack or harassment by adult male seals. In early 1991 nine monk seals with evidence of injury as a result of interaction with the longline fleet were reported or observed.

Sea turtle interactions with the longline fishery in the NWHI were also reported for this period. During the NMFS field surveys conducted in May 1990, a green turtle was found on Trig Island at French Frigate Shoals with monofilament line similar to longline leader protruding from its mouth.[13] Olive ridley, loggerhead, and green turtles have been reported taken on baited hooks and snagged on longline hooks in the NWHI[14], but there is some question regarding identification of the species involved. Regardless, preliminary analysis of logbook data from the Hawaii longline fishery indicates a significant take of sea turtles. For 1991, 61 total takes with 3 mortalities were reported. Leatherback turtles constituted the largest percentage of turtles taken (61%, 38 individuals) and green turtles were reported as the second highest (31%, 19 individuals)[15].

Based on logbook reports false killer whales are identified as taking catch in all pelagic longline fisheries as has been reported in other longline fisheries in the Pacific. A 1990 observer report described catch loss to a solitary killer whale, *Orcinus orca*, on one set in mid-Pacific waters (Dollar[16]). In 1991 a humpback whale was observed entangled in longline gear in the EEZ off the NWHI (Dollar[16, 17]) and a second was reported entangled in longline gear off Lanai.

From January through September 1992, longline logbook data indicated up to 68 albatrosses killed or injured over 947 reported trips. There is no distinction made in the logbooks between species of albatrosses.

Other Fisheries

Inshore Monofilament Gillnets

Small-mesh (about 5 cm stretched mesh) gillnets are commonly set on the shallow reefs around all the main islands and allowed to soak overnight, usually in water less than 10 m depth. In 1992–93 the State of Hawaii received 288 applications for permits that listed nets as the primary gear. Gill net was specified in 161 additional applications for permits. This fishery targets inshore reef fish.

Interactions with protected species have been reported. One bottlenose dolphin calf was recovered from a gill net off Maui in 1991[18], but bottlenose

[12]NMFS field survey report. May 18, 1990. Southwest Fish. Sci. Cent., Honolulu Lab., 2570 Dole St., Honolulu, HI 96822–2396.

[13]See footnote 12.

[14]NMFS longline logbook reports, 1991. Pacific Area Office, Southwest Region, 2570 Dole St., Honolulu, HI 96822–2396.

[15]See footnote 14.

[16]R. A. Dollar. 1991. Summary of swordfish longline observations in Hawaii, July 1990–March 1991. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-91-09, 13 p.

[17]See also footnote 11.

[18]Stranding Report ETN 91–03, Hawaii Marine Mammal Stranding Network. Pacific Area Office, Southwest Region, 2570 Dole St., Honolulu, HI 96822–2396.

dolphins are rarely reported entangled or raiding set gill nets in Hawaii; this is somewhat surprising, since they readily remove akule, opelu, bottomfish, and small tunas from handlines and trolling lines.

There are records of spinner dolphins being taken in nets or net fragments in Hawaiian waters (Rizzuto, 1988, 1989), and there is an eyewitness account of a spinner dolphin removed from an inshore gillnet on Oahu and buried on the beach in 1990[19]. One confirmed interaction between Hawaiian monk seals and inshore monofilament gill nets has been reported from the main Hawaiian Islands. A Hawaiian monk seal was reported drowned in a gill net near Poipu, Kauai, in 1976[20]. Green turtles are periodically caught in inshore monofilament gill nets set around the main Hawaiian Islands. At least 43 (25%) and possibly as many as 86 (50%) of the 171 dead green turtles stranded in Hawaii in 1991 were likely entangled in these gill nets[21]. A hawksbill turtle was recovered from a monofilament gill net in Kaneohe Bay, Oahu, in 1977 (Balazs, 1978).

Lobster Fishery

The commercial spiny lobster fishery around the main Hawaiian Islands represents a small percentage of Hawaii's total fishery. The primary commercial fishing grounds are found in the NWHI, and the fishery is governed by a Federal fishery management plan. Consistent commercial-scale operations began in the NWHI in 1976, with most vessels processing frozen lobster tails on-board and a few vessels delivering live lobster to a specialized market.

Gear used initially in the NWHI fishery was a version of the California two-chambered trap or the wooden-lath Florida pot, deployed on a main line and spaced at intervals of 2 to 10 m. Each main line had 75 to 150 traps, and vessels carried an average of 300 traps. Traps were set each day before sunset between 55 and 90 m depth, fished overnight, and retrieved the next morning. By 1985 virtually the entire fleet of 16 active vessels (compared with 4 active vessels in 1983) had converted to the black plastic crab pot which is used in the Alaska crab fisheries. This dome shaped pot is single chambered, has two entrance funnels, and can be folded in half to increase a vessel's trap carrying capacity. Between 1983 and 1985, during the conversion from the two-chambered California pot and Florida pot to the black plastic trap, the number of active vessels increased from 4 to 16 and the total trap carrying capacity of the active fleet increased from 1,200 to 12,250. From 1983 to 1990 the average trap carrying capacity of the lobster vessels in the NWHI fleet increased from 300 to over 1,000, with the number of active vessels fluctuating between 4 and 16 (Dollar and Landgraf[22]). The black plastic pots are fished in the same manner as the old traps.

A monk seal was entangled and drowned in the trap bridle and main lines of a string of lobster traps in the vicinity of Necker Island in 1986[23]. This is the only reported mortality of a Hawaiian monk seal associated with the spiny lobster fishery in the NWHI since the Crustaceans Fishery Management Plan (FMP) went into effect in 1983. In 1980 an adult leatherback turtle was entangled in a mainline of a string of lobster traps near Kure Atoll. The turtle was released alive (Humphreys[24]).

Miscellaneous and Unidentified Gear

Reports between 1986 and 1992 of at least three incidents of humpback whales dragging unidentified pieces of netting around Kauai and Maui appear to demonstrate that some interaction between whales and fisheries occurs. The disposition of these animals is unknown, as are the sites where entanglements occurred. In 1992 a humpback whale mother and calf were found entangled off the east coast of the island of Hawaii in gear similar to longline deployed from shore. The animals were subsequently disentangled and released alive by the U.S. Coast Guard (ETN, personal observ.).

Green turtles have been reported hooked and entangled in the flippers and body and taken on baited hooks from shoreline pole-and-line fishermen around the main Hawaiian Islands[25]. Protected species, especially Hawaiian monk seals and often green sea turtles, are susceptible to entanglement in lost and discarded fishing equipment, including lines, nets, and other plastic flotsam. These entanglements represent secondary interactions, i.e., interactions with gear no longer actively being used, and as such are beyond the scope of this paper. However, it is often difficult to determine whether an entanglement occurred during active fishing or after the gear had been lost.

Research

The first reports of attempts, such as shooting, to deter bottlenose dolphins from taking catch were received by the NMFS in the early 1970's. Although many methods were tried to deter predation by dolphins, none proved successful. Methods included rigging live baits with wire, hooks, or foil to confound the animals' sonar (Schlais, 1985), injecting citric acid into the baits to develop a taste aversion for certain species of fish[26], and using various

[19]M. Hoffhines. University of Hawaii, Kewalo Basin Marine Mammal Laboratory, 1129 Ala Moana Blvd., Honolulu, HI 96814. Personal commun. 1992.

[20]Internal NMFS stranding report, March 16, 1976. Pacific Area Office, Southwest Region, NMFS, Honolulu, HI 96822–2396.

[21]G. Balazs. Southwest Fisheries Science Center, Honolulu Laboratory, 2570 Dole St., Honolulu, HI 96822–2396. Personal commun. 1991.

[22]R. A. Dollar and K. C. Landgraf. 1992. Annual report of the 1991 western Pacific lobster fishery. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-92-10, 26 p.

[23]NMFS lobster logbook report, November 1986. Pacific Area Office, Southwest Region, NMFS, 2570 Dole St., Honolulu, HI 96822–2396.

[24]R. L. Humphreys, Jr. 1981. Hawaiian monk seals and sea turtle — sightings and direct interactions with fishing operations in the Northwester Hawaiian Islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-81-6, 18 p.

[25]G. Balazs. Southwest Fisheries Science Center, Honolulu Laboratory, 2570 Dole St., Honolulu, HI 96822–2396. Personal commun. 1992.

[26]J. J. Naughton. 1981. Trip report on porpoise-fisheries interaction, Kona, Hawaii, November 2–4, 1981. Pacific Area Office, Southwest Region, Natl. Mar. Fish. Serv., Honolulu, HI 96822–2396. Unpubl. rep. 4 p.

noisemakers including explosive, mechanical, and electronic devices. The unconfirmed use of poisons in bait was also reported during this time. Food aversion was investigated by the NMFS in 1980[27] as a potential method of deterring cetaceans. The results proved inconclusive. Complaints to NMFS from fishermen continue and appear to peak in cycles of 3 to 5 years, covering all fisheries from longline and live bait troll fisheries for pelagic species to handlining for bottomfish and mackerel scad.

Sound generators were tested on pinnipeds in California and Oregon with mixed results. In some cases the acoustic harassment was successful in initially deterring pinniped predation on various species of fish. However, the animals either habituated to the sounds or ignored them (Mate and Harvey, 1987). Masking or confusing sounds proved ineffective.

Any future investigations of aversive techniques for small cetaceans will have to consider stimuli strong enough to be physically painful but not injurious, particularly under the current regulatory regime. This is particularly difficult because of the behavior and adaptability of bottlenose dolphins and perhaps other species such as false killer whales to new stimuli. The attraction for food is secondary, and the challenge or stimulus of taking fish may be the primary motivating factor for some individual animals. The use of aversive techniques may provide greater motivation for these animals to solve the "problem" or "play the game."

Other avenues of research which could be considered are the use of conspecific social sounds that indicate threat or alarm which might serve to confuse some of the more socially oriented small cetaceans and the use of pheromones as distractants.

There has been no directed investigation of alternative fishing methods or other means of reducing the potential for incidental take in Hawaii. Most of the effort to reduce incidental take of sea turtles results from regulatory actions that limit fishing effort through closed areas and limited entry and restrictions on the level of allowable incidental take. Altered fishing methods may serve to diminish seabird interactions in the longline fishery (Brothers, 1991). Setting and retrieving gear during the night, a voluntary measure taken by longline fishermen, appears to have reduced the incidental take of seabirds in this fishery.

Management and Regulation

Statutory and Regulatory Implications

Since 1972 various regulatory regimes have been implemented in response to fishery interactions. The Endangered Species Act of 1973 (ESA) and the Marine Mammal Protection Act of 1972 (MMPA) are the two primary Federal statutes that protect marine mammals and threatened and endangered species in Hawaiian waters, and the Migratory Bird Treaty Act of 1918 protects seabirds. The Magnuson Fishery Conservation and Management Act of 1976 (MFCMA) also provides management authority to protect these species in fisheries governed by FMP's.

The ESA prohibits the taking of endangered species except under limited circumstances. These include, but are not limited to, scientific research under permit, actions taken by personnel authorized by the NMFS or USFWS to salvage or rescue a stranded or distressed endangered animal, and an allowable level of take (except for certain marine mammals) set forth during consultation for a specific Federal activity under Section 7 of the ESA. Incidental take of listed sea turtles may be authorized, but no take can be authorized for Hawaiian monk seals or humpback whales.

The MMPA allows the incidental take of marine mammals during commercial fishing operations under certain conditions. Depleted marine mammal species, including Hawaiian monk seals, cannot be intentionally lethally taken. Under the 1988 amendments to the MMPA, some levels of mortalities of nonendangered and nondepleted marine mammals have been determined for specific fisheries. Nonlisted cetaceans may be taken incidentally or harassed, but not intentionally killed or injured, again for specific fisheries.

Historic Context

Prior to 1988 the MMPA allowed the NMFS to issue general incidental take permits to commercial fishermen operating within the U.S. EEZ. This exception to the general moratorium on the taking of marine mammals was permitted provided that the marine mammal stocks involved were within OSP[28] levels, that the takings would not disadvantage the stocks, and that the issuance of the permits were consistent with the purposes and policies of the MMPA.

From 1981 to 1988 commercial fishermen operating in Hawaiian waters who participated in fisheries affected by small cetaceans were covered under a general permit which allowed harassment of these animals without injury or mortality. Reports of harassment were required under the permit, but few were actually received. Complaints of catch loss far exceeded reports of harassment. The high point of participation occurred in 1982 when 77 certificates of inclusion were issued to commercial fishermen allowing them to operate under the general permit. Since 1988 there have been few written reports of interactions from non-FMP regulated fisheries in Hawaii. An estimate of economic loss to the various fisheries has not been made but may be substantial in relation to the size of the fisheries.

A district court ruling in 1987 invalidated a permit issued to a Japanese fishing cooperative for the incidental taking of Dall's porpoise because species for which permits could not be

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[27]B. A. Kuljis, C. S. Baker, and W. G. Gilmartin. 1981. Effects of lithium chloride on a Pacific bottlenose dolphin (*Tusiops gilli*). Presented abstract, Fourth Biennial Conference on the Biology of Marine Mammals, December 14–18, 1981, San Francisco, Calif.

[28]OSP (optimum sustainable population) as defined in the MMPA means, ". . . with respect to any population stock, the number which will result in the maximum productivity of the population or the species, keeping in mind the carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element." Marine Mammal Protection Act of 1972, 86 Stat. 1027, 16 U.S.C. 1361–1407, P. L. 92–522.

issued would also be taken during fishing operations. Under this judicial interpretation NMFS could issue permits for only a few species of marine mammals for which OSP levels were known (none in Hawaii). In order to provide a temporary means of obtaining reliable information about marine mammal/fisheries interactions, while allowing commercial fishing to continue, Congress passed the 1988 Amendments to the MMPA which established the Interim Exemption for Commercial Fisheries (Interim Exemption). Under the Interim Exemption fisheries were categorized according to the likelihood of incidentally taking marine mammals. Observer programs to monitor marine mammal interactions and reporting requirements were also established by the Interim Exemption.

All domestic Hawaiian fisheries have been classified by NMFS as Category III, with incidental takings of marine mammals unknown and/or considered extremely unlikely. This does not mean that no interactions occur, only that marine mammals would not normally be hooked, snagged, injured, or killed during fishing operations. Interactions as well as accidental lethal takes are to be reported to the NMFS.

The Interim Exemption expired 1 October 1993. The NMFS was required to develop a regime to govern the incidental taking of marine mammals associated with commercial fishing operations after 1 October 1993.

Fishery Management Plans

Four FMP's are in effect in the U.S. EEZ around Hawaii—Precious Corals, Crustaceans, Bottomfish, and Pelagics. Protective measures for marine mammals and threatened and endangered species are generally incorporated into FMP's as they are developed. Because of concerns regarding interactions between Hawaiian monk seals and the spiny lobster fishery in the NWHI, specific conservation measures were incorporated into the Crustaceans FMP as it was being developed. These measures included closed areas within 10 fathoms of the islands in the NWHI, a 20-mile fishing refugium around Laysan Island, a trap opening size restriction of 6.5 inches, NMFS authority to place observers on lobster vessels upon request, and a protocol by which the NMFS could institute emergency protection for monk seals if a problem involving the fishery arose. Only the fishery for precious corals has not reported an interaction with marine mammals, sea turtles, or sea birds in fisheries governed by the four existing FMP's.

Section 7 consultations under the ESA for the Crustaceans, Bottomfish, and Pelagics FMP's concluded that these fisheries would not likely jeopardize the continued existence of the Hawaiian monk seal if certain gear and reporting requirements were included in the implementing regulations for these fisheries. Because of recent developments in the broadbill swordfish fishery, the Pelagics FMP is now being monitored based on Section 7 requirements. The longline fishery and bottomfish fishery are discussed together in this section because the management issues are tied to the geographic area of the NWHI and involve interactions with Hawaiian monk seals.

Allegations of Hawaiian monk seal interactions with the longline broadbill swordfish fishery in the NWHI surfaced in April 1990. NMFS field surveys in May 1990 found seven injured Hawaiian monk seals in the NWHI with possible evidence of interactions with the longline fishery. Subsequent interviews by NMFS special agents with captains and crews of 28 vessels returning from the NWHI did not generate sufficient information for enforcement action. However, there was enough consistency in reports to indicate that measures were needed to obtain definitive information on possible impacts on protected species from the longline and bottomfish fisheries.

In June 1990 the Western Pacific Fishery Management Council (Council) considered this issue. The Council proposed that NMFS implement the following: 1) A permit and logbook reporting system for the pelagic longline fishery and 2) a program to place observers on selected longline and bottomfish vessels operating in the NWHI. Although not required by regulation, observers were placed aboard one bottomfish and six longline vessels on a voluntary basis between July and October 1990 and reported interactions with sea birds, sea turtles, whales, dolphins, and monk seals. Emergency regulations were subsequently implemented by the NMFS in November 1990 restricting longline and bottomfishing operations within 50 n.mi. of selected islands in the NWHI (protected species zone). This was intended to provide a "safe zone" where Hawaiian monk seals were most likely to occur. These restrictions were waived on a trip by trip basis however, provided the operator of the vessel allowed NMFS the opportunity to place an observer aboard to document and describe interactions with protected species.

Concerns increased after further reports, in January 1991, of monk seals observed with hooks (long pieces of monofilament line attached) imbedded in their bodies and with severe injuries that appeared to be the result of interactions with fishing operations. As a result the protected species zone was expanded to include all NWHI and was closed to longline fishing in April 1991, through emergency regulation.

Amendments were subsequently implemented to both the Bottomfish FMP and the Pelagic FMP making these emergency regulations permanent. Specifically, Amendment 4 to the Bottomfish FMP restricted bottomfishing in the protected species zone which includes the area within 50 n.mi. of the islands and atolls in the NWHI from Nihoa Island to Kure Atoll. These restrictions can be waived on a trip by trip basis however, provided the operator of the vessel allows NMFS the opportunity to place an observer aboard. Amendment 3 to the Pelagics FMP prohibited fishing in the protected species zone which includes the 100 n.mi. wide corridors between islands in the NWHI where the zones are not contiguous. Logbook reporting of interactions is also required of longline vessels in order to obtain information regarding interactions outside the protected species zone.

Observer coverage became mandatory in November 1990 for bottomfish

vessels because of the proximity of their fishing operations to the banks and islands of the NWHI, and the evidence of interactions between protected species and the fisheries in this area. The area from Nihoa Island to Necker Island comprises the Mau Zone. The Ho'omalu Zone is a limited entry fishing zone and comprises the area from French Frigate Shoals to Kure Island (Fig. 2). All vessels which bottomfish in either the Mau or Ho'omalu Zones are required to place onboard observer selected by NMFS. Target observer coverage is currently set at 30 percent annually.

Future Prospects

The probable trends in protected species/fishery interactions in Hawaii are difficult to assess, but interactions will likely increase. Fishing effort is also likely to grow and place the various fish stocks under greater pressure, as an increasing human population demands more food resources. With the protection afforded by the ESA and MMPA, certain species, such as the humpback whale, will probably continue to recover from the low levels to which they were reduced by exploitation, and such increases may result in more interactions. Finally, continued environmental awareness, together with increased fishing pressure, will likely result in greater scrutiny of fisheries, resulting in more restrictions, regulations, and reporting requirements. Regardless of the difficulties in predicting trends and developing solutions for protected species/fisheries interaction problems, at the minimum, the variables that need to be monitored include population levels of the different species involved, fishing effort, and rates of interaction.

The following research and management tasks address both long- and short-term needs for the conservation and protection of marine mammals and other protected species in Hawaiian waters.

1) Accurate, timely, and consistent documentation of interactions;

2) Elimination of inshore gillnets and set nets;

3) Assessment of the status of stocks of all protected species which interact with fisheries;

4) Development of alternative fishing methods which reduce or eliminate interactions with small cetaceans; and

5) Where interactions cannot be eliminated or mitigated by other means, development of management schemes which allow for incidental take of selected species of marine mammals in Hawaiian waters provided that the stocks of marine mammals are not adversely affected.

Many of the tasks identified above rely upon the cooperation of a number of agencies and will be affected by the restrictions and requirements of the applicable Federal and state statutes. Given the biology of the protected species involved in fishery interactions, the current and likely future regulatory regimes, and the nature and locations of the Hawaiian fisheries, the interaction problems identified ultimately may have no legal or practical solutions.

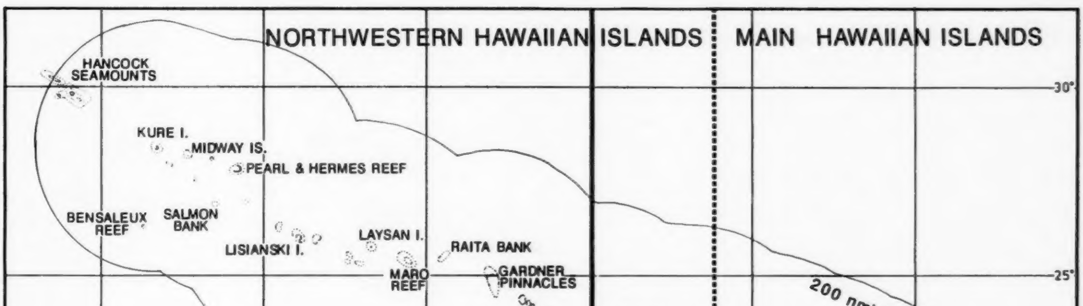

Figure 2.—Northwestern Hawaiian Islands bottomfish management areas.

Acknowledgments

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Economics and Hawaii's Marine Fisheries

SAMUEL G. POOLEY

Introduction

Fishing and seafood consumption permeate society in Hawaii, although neither the total volume of seafood harvesting nor the market value of seafood is a particularly large share of the state's economic activity.[1] Seafood consumption is an integral aspect of Hawaii's culture, from traditional Polynesian uses of nearshore and reef species to the importance of seafood in Asian cultures. As a result of cultural adaptation by the rest of the population and energetic promotion of local seafood in restaurants oriented toward tourism, per capita seafood consumption in Hawaii is high, and a very large percentage is fresh fish (Higuchi and Pooley[2]; East-West Research Inst.[3]).

Fishing and seafood marketing also have been important bridges into commercial society for several immigrant groups, from the Japanese, Chinese, and Portuguese who came to Hawaii as plantation workers at the turn of the century to Koreans and North Americans who came for more varied reasons over the past 20 years. Fishing has also been important in tourism, particularly for Kailua-Kona on Hawaii (the Big Island), through the promotion of deep-sea fishing and sport fishing tournaments.

Hawaii is not the "paradise" promoted by the tourism industry, although probably for most people living here it is the only place to live. Hawaii is a densely populated state,[4] with an economy dominated by tourism (as much as 50% of the gross state product) and with a natural resource policy dominated by land use and coastal zone development issues. Nonetheless, subsistence fishing in rural areas and recreational fishing for city residents are important releases from urban culture, as well as sources of food and income.

With this in mind, the following sections attempt to delineate important components of the economics of Hawaii's fisheries. However, there has been no comprehensive survey of recreational and subsistence fishing activity in Hawaii, and economic surveys have been episodic. Thus the information with which to estimate the economic value of the Hawaii fishery is limited.

Economic Values

Determining the economic value of Hawaii's marine fisheries is not simply a process of adding up commercial values, nor the straightforward valuation of subsistence and recreational resources and cultural practices, nor even a recitation of the kind of economic processes which affect the use, development, and management of these resources. The common yardstick for determining the economic value of commercial fisheries is ex-vessel revenue from the sale of harvested fish (and shellfish). In Hawaii, where there is essentially no processing industry, this is a good start. Ex-vessel revenue from Hawaii's commercial fisheries has been estimated at $50 million in 1990 (Pooley, unpubl. data).[5] This revenue was generated from 21 million pounds (9,500 t) of marine fish landed in Hawaii by Hawaii-based fishing vessels. The composition of ex-vessel revenue by the major fleet components is shown in Figure 1.

However, there are three additional direct components to the economic value of Hawaii's marine fisheries: recreational fishing values, subsistence fishing values, and charter fishing values.[6] First, it is important to realize that the distinction between "commercial" and "recreational and subsistence" fishing in Hawaii is a weak distinc-

[1]The ex-vessel value of Hawaii's commercial fishery is less than 2/10% of gross state product, while the wholesale value of the seafood market (including imports) is less than 5/10%. (General statistics for Hawaii are taken from the State of Hawaii Data Book, 1990. Dep. Planning and Econ. Development. Honolulu, Hawaii.)

[2]W. K. Higuchi and S. G. Pooley. 1985. Hawaii's retail seafood volume. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-85-06, 16 p.

[3]East-West Research Inst. 1989. Hawaii seafood consumption: a survey of seafood consumption in Hawaii. Contract Rep., State of Hawaii, Dep. Business and Economic Development, Honolulu, Hawaii.

[4]The Island of Oahu, on which Honolulu sprawls, has a density greater than New Jersey, the most densely populated state.

[5]The nominal (not adjusted for inflation) ex-vessel revenue from commercial fishing was $3.9 million in 1970, $13.0 million when adjusted for inflation to 1990 consumer price levels.

[6]We exclude the lucrative ocean recreation sector, as well as the aquarium fish market and dive shops since these rely primarily on inshore and reef resources.

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ABSTRACT—This paper reviews economic research conducted on Hawaii's marine fisheries over the past ten years. The fisheries development and fisheries management context for this research is also considered. The paper finds that new approaches are required for marine fisheries research in Hawaii: A wider scope to include other marine resource and coastal zone issues, and increased and closer collaboration between researchers and the fishing community.

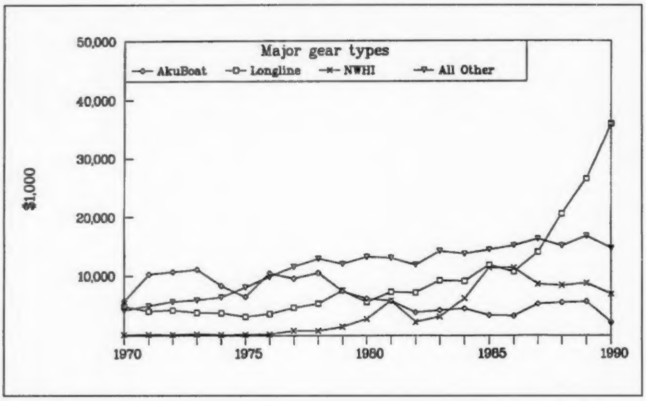

Figure 1.—NMFS estimates of commercial fishing revenue, adjusted for inflation, by major fleet components, 1970–92.

tion. The State of Hawaii commercial fishing license is quite inexpensive, and enforcement of its requirements is limited. A survey in 1984 found that 27% of small boat[7] owners sold a portion of their catch and 17% sold at least half their catch (Skillman and Louie[8]). Further study by Meyer[9] found that 35% of small boat catches were sold on the market and 13% were sold "off" the market, while 23% were retained for home consumption and 21% were given away to family and friends.

The overall level of recreational and subsistence fishing activity is difficult to assess. Meyer[9] estimates that the total catch by small boat fishermen (including some commercial landings) in 1985 was approximately 21 million pounds, of which 10 million pounds were sold. These are substantial numbers for Hawaii, when the recorded commercial fish landings by the small boat fleets was 5 million pounds in 1985.[10] The NMFS Marine Recreational Fishing Statistical Survey (MRFSS) which has served as the basic yardstick for recreational fishing landings (in weight and number, not value) across the mainland U.S. has not been conducted in Hawaii since 1981, and the results from the 1979–81 survey in Hawaii were not published. However, the unpublished MRFSS estimates suggest the volume of small-boat noncommercial marine landings in Hawaii was roughly 9 million pounds a year in that time period.[11] Assuming some positive relationship between small-boat commercial and noncommercial volume, there is no evidence from small-boat commercial landings in the late 1980's to suggest any dramatic change in the relative volume of the noncommercial sector. Furthermore, in a recent study reported by Hamm and Lum[12], recreational and subsistence landings (i.e., fish landed but not for sale) for the Island of Oahu amounted to 1.9 million pounds, based on a year-long small-boat survey. This amounted to 59% of the landed weight by these vessels (which excluded the charter boat fleet operating out of the Port of Honolulu and other larger commercial trolling vessels).

The monetary value of recreational and subsistence landings is even more difficult to assess, and comparison between the monetary value of recreational landings and commercial landings is a complex theoretical, indeed philosophical, issue. Meyer[9] estimated that the market value of the fish sold by recreational and subsistence fishermen was approximately $30 million (adjusted for inflation to 1990 price levels). However, the hedonic (or nonmarket) value of the recreational fishing experience was estimated at $335 million (inflation-adjusted) from direct expenditures on small-boat recreational and subsistence fishing of $33 million (inflation-adjusted). Since there are complex personal motivations for recreational and subsistence fishing, it is difficult to assess how much of this value should be associated with landing the fish, per se, and how much to other motivations.

In terms of participation, Skillman and Louie[8] estimated that there were at least 5,000 small boats actively used for fishing in Hawaii. The State of Hawaii recorded 3,500 commercial fishing licenses for fiscal year 1989, but this included licenses for crews on large-scale commercial fishing vessels as well as for small-boat fishermen. The state registers 1,100 vessels as commercial fishing boats (1989), but this excludes the larger vessels (documented by the U.S. Coast Guard), and choice of registration categories is somewhat dependent on tax status.

Figures on the level of recreational fishing activity in Hawaii are not entirely consistent. The MRFSS estimated the number of boat fishing trips in 1979–81 at 0.5 million annually. However, this amounts to over 1,350 trips per day, which seems excessive. Meyer[9] estimated that the average par-

[7]"Small boat" is a ubiquitous term referring primarily to troll, handline, and dive fishing vessels under 45 feet in length overall.

[8]R. A. Skillman and D. K. H. Louie. 1984. Inventory of U.S. vessels in the central and western Pacific: Phase 2—verification and classification. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-84-12, 21 p.

[9]Meyer Resources Inc. [P.A. Meyer]. 1987. A report on resident fishing in the Hawaiian islands (a project to determine the economic value of recreational fishing in Hawaii). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-87-8C, 74 p.

[10]Unfortunately there is believed to be substantial underreporting in the state data. The extent of this underreporting for small boats is unknown.

[11]There was tremendous year-to-year variation in the estimates provided by the MRFSS survey which is primarily attributable to variation in number of fish landed and by average weight of fish (a composite of species composition and average weight per species). Clearly there were some substantial estimation problems with this survey approach, but the estimates probably indicate the relevant range of these fisheries.

[12]D. C. Hamm and H. K. Lum. 1992. Preliminary results of the Hawaii small-boat fisheries survey. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab, Southwest Fish. Sci. Cent. Admin. Rep. H-92-08, 35 p.

ticipation by small-boat fishermen was 38 trips per year, which would lead to an estimated 13,200 people who participated in small boat fishing in the mid-1980's. This seems like a generous number of trips per year (as an overall average) and a conservative number of actual participants. Until a comprehensive survey is conducted, these figures will remain elusive.

The value of fishing for subsistence by contemporary native Hawaiians and others has also not been calculated, but it is known to be an important component of some communities, particularly rural communities. Fish also have played an important cultural role. Iversen et al., in a study of anthropological sources, noted:

"There is abundant historical and archaeological evidence for the social and religious importance of bottomfish, aku (skipjack tuna), and sharks in traditional Hawaiian culture .... At the family level, sharks and aku were often conceived as 'aumakua — family or personal gods. The boundary between the supernatural world of these personal gods and the natural world of the Hawaiian people was not sharply defined" (Iversen et al.[13]).

For this paper I will not attempt to place a monetary-value estimate on subsistence fishing (separate from that identified above by Meyer[9]), except to acknowledge its importance.

Finally, Samples et al.[14] and Samples and Schug[15] estimated that the direct market value of charter boat fishing (i.e., the fees paid by patrons) was $8.5 million (inflation-adjusted) annually. At that time the charter boat fleet consisted of approximately 120 boats which took 75,000 trips annually. The charter boat fleet is understood to have grown fairly substantially over the past decade, particularly on the neighbor islands and in rural Oahu.

There is no direct comparison between the ex-vessel value of commercial fishing landings and the direct revenues of charter boat fishing, on the one hand, and the expenditures and hedonic values of recreational and subsistence fishing, on the other hand. Furthermore, there is substantial overlap in the estimates of landings by the small-boat fleets. However, a rough estimate of the direct input costs for all types of fishing combined would be $100 million[16]. Table 1 presents estimates of landings (pounds) for both sectors and dollar values for the commercial sector, including the seafood markets.

Only for commercial fishing can we estimate long-term trends in economic values. These appear in Figures 2 and 3. Inflation-adjusted ex-vessel revenue increased almost fourfold from 1970 to 1990, with dramatic increases in the past five years (threefold) owing to the

[16]Data on charter boat and recreational costs taken from Samples (1984, 1985), and the unpublished MRFSS for 1979-81. Commercial fishing costs were estimated to be equal to commercial fishing ex-vessel revenue.

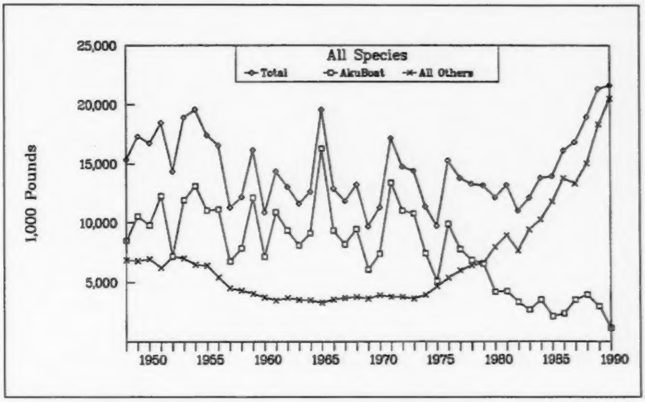

Figure 2.—NMFS estimates of commercial fishing landings, 1948–91.

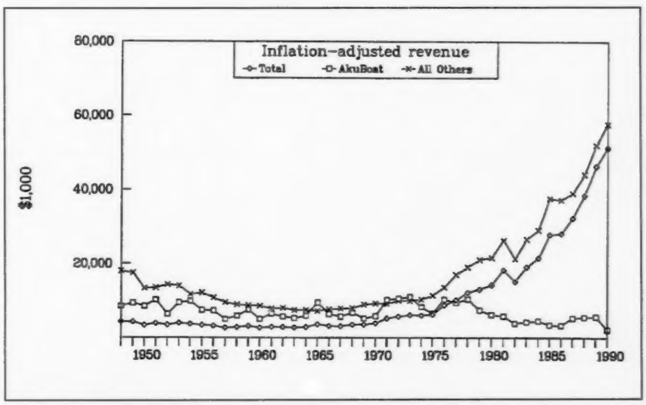

Figure 3.—NMFS estimates of commercial fishing revenue, adjusted for inflation, 1948–90.

[13]R. Iversen, T. Dye, and L. M. B. Paul. 1989. Rights of native Hawaiian fishermen with specific regard to harvesting bottomfish in the Northwestern Hawaiian Islands and with regard to harvesting bottomfish, crustaceans, precious corals, and open-ocean fish in offshore areas surrounding the entire Hawaiian island chain. A report prepared for the Western Pacific Regional Fishery Management Council. Honolulu, Hawaii.

[14]K. C. Samples, J. N. Kusakabe, and J. T. Sproul. 1984. A description and economic appraisal of charter boat fishing in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-84- 6C, 130 p.

[15]K. C. Samples and D. M. Schug. 1985. Charter fishing patrons in Hawaii: a study of their demographics, motivations, expenditures and fishing values. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-85-8C, 95 p.

Table 1.—NMFS estimates[1] of Hawaii fishery components, 1990. MHI = Main Hawaiian Islands; NWHI = Northwestern Hawaiian Islands.

Hawaii seafood supply and market, 1990 wholesale purchase level NMFS estimates (1,000's)

Source of supply	Pounds	Dollars
Commercial fishing[2]	21,000	50,400
Recreational fishing[3]	9,200	
Hawaii fishery	30,200	50,400
Foreign imports[4]	15,600	29,800
U.S. mainland "imports"[5]	24,300	46,500
Export (foreign and U.S. mainland)[6]	3,400	8,200
Hawaii consumption[7]	66,700	
Hawaii market (commercial)[8]	57,500	118,500

Hawaii commercial fisheries, 1990 NMFS estimates based on logbooks and shoreside monitoring NMFS estimates

Fleet	Pounds caught	Pounds sold	Dollar
Longline	13,090	12,200	28,800
MHI troll-hand	4,460	4,050	6,980
Aku boat	1,005	1,005	1,838
MHI bottomfish	830	810	3,300
NWHI bottomfish	420	400	1,070
NWHI lobster	949	949	4,887
Other	1,700	1,594	3,513
Total	22,454	21,008	50,388

[1] Honolulu Laboratory, National Marine Fisheries Service, Fishery Management Research Program.
[2] Hawaii commercial fishing: Domestic landings estimated by detailed NMFS logbooks and shoreside sampling, augmented by available State of Hawaii data for nonsampled fisheries.
[3] Recreational: Volume estimated in 1981 by NMFS Marine Recreational Fishing Statistical Survey.
[4] Foreign imports: volume (pounds) recorded by U.S. Food & Drug Administration monitoring; revenue estimated from Honolulu market prices by NMFS.
[5] U.S. mainland "imports": Volume and revenue estimated as proportion of Foreign imports using raising factors calculated from 1981 NMFS seafood market survey in Hawaii.
[6] Exports: Estimated from domestic landings of lobster, bottomfish, swordfish, and bigeye and yellowfin tuna.
[7] Hawaii consumption: Hawaii fishery + Imports – Exports.
[8] Hawaii market: Hawaii consumption – Recreational.

growth of the domestic longline fishing fleet. With a change in species and product composition from cannery tuna (34% of landings in 1980) to highly valued species (frozen lobster tails and fresh tunas, pelagics, and bottomfish), the inflation-adjusted price of fish in Hawaii also has risen dramatically, doubling from 1970 to 1990.

While it appears that some substantial profits have been made by some highliner sectors of the fishing fleet for short periods of time (e.g., the NWHI lobster fishery in the mid-1980's and the more technologically advanced swordfish boats in recent years), like most fisheries, Hawaii's commercial fishing sector provides employment and income more than an independent source of wealth. Many fisheries are characterized by limited profitability and declining incomes, and participation in commercial fisheries other than longline has probably been stable or declining (and there is a moratorium on entry into the longline fishery and the NWHI bottomfish and lobster fisheries). The seafood marketing sector may have a more stable profit-basis, but its competitiveness also suggests that capital income is relatively limited. This makes the public policy issues of fisheries management and development much more pointed than might be believed.

Fishery Development

Fisheries development economics is a difficult blend of industry economics and the bioeconomics of fisheries management. Some of these problems have been considered in a planning context (Pooley[17]) which suggests that an interactive approach to fisheries development and management may be a more fruitful means for long-term sustainable development. However, most of the fisheries development work in Hawaii has been more traditional in its orientation, and there was relatively little conceptual work investigating the framework of fisheries development (Pooley[18]).

Throughout the late 1960's and the 1970's, fishery development was the predominant fisheries theme in Hawaii. The Pacific Tuna Development Foundation (PTDF)[19] was a joint State/Territory-Federal-industry body which initiated development projects throughout the Pacific, from advanced purse seine techniques which led to the initial movement of the U.S. tuna fleet from southern California to the western Pacific (primarily Papua New Guinea), to small-scale development activities such as teaching handline fishing techniques and building new boat launching ramps. The State of Hawaii through its Department of Land & Natural Resources sponsored the Hawaii Fishery Development Plan in 1979 (Hawaii Department of Land & Natural Resources[20]) which proposed a multi-million-dollar program of capital improvements and development projects aimed at establishing Hawaii as a base for distant water commercial fishing[21] and reinvigorating local fisheries[22]. Much of the NMFS research during this period was also directed toward fisheries development, including the tripartite study of the essentially uninhabited Northwestern Hawaiian Islands (NWHI) in the late 1970's (Grigg and Pfund, 1980). This study identified important lobster fishing grounds which at one point grew to be Hawaii's most lucrative single fishery ($6 million ex-vessel revenue in 1989).

Two important exogenous changes altered the climate for Hawaii's commercial fisheries during this period. In the mid-1970's, the increase in frequent neighbor island jet flights made possible the expansion of the domestic market for neighbor island fresh fish to Honolulu. This assisted the development of the neighbor island handline tuna and bottomfish fisheries. Furthermore, with the tremendous expansion of tourism and jumbo jet traffic between Hawaii and the mainland U.S. and between Hawaii and Japan, fresh

[17]S. G. Pooley. 1989. The role of government planning and economic analysis in the development of the private fisheries sector. Southwest Fisheries Center, Honolulu Laboratory manuscript MRF-003-90H, paper contributed to the International Symposium on Agriculture and Fisheries Development in Oman, Muscat, Oman.

[18]S. G. Pooley. 1985. The hopelessness of the invisible hand: small versus large fishing vessels in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-85-02, 16 p.

[19]Later renamed the Pacific Fishery Development Foundation.

[20]Hawaii Dep. of Land and Natural Resour. 1979. Hawaii Fisheries Development Plan. Dep. of Land and Natural Resources. State of Hawaii, Honolulu, Hawaii.

[21]Such as domestic purse seining (C. D. MacDonald and J. A. Mapes, 1985. Hawaii as a base for tuna purse seining operations. State of Hawaii, Dep. Planning and Econ. Develop., Honolulu, Hawaii).

[22]A parallel effort was made to develop onshore aquaculture (Hawaii Dep. Business and Economic Development, 1978), and despite a number of business failures, the wholesale value of aquaculture products produced in Hawaii was $9 million in 1990 (Corbin, 1992).

fish from Hawaii gained new adherents and easier access to these external markets. This has been particularly true of the longline fishery, which reached its nadir in the late 1970's and which expanded steadily through the 1980's until the discovery of the swordfish fishery, at which point longlining exploded in volume. The closure of the Honolulu tuna cannery in 1984, coincident with worldwide changes in the structure of the U.S. tuna industry, reduced the basic infrastructure available for the commercial fishery for a number of years and also changed the low end of the tuna market (with increased supplies of fresh skipjack tuna competing with yellowfin tuna caught by handline vessels). No substantial alternative market has been developed for skipjack tuna, despite marketing assistance from two state agencies, the aku boat fleet has declined substantially, and the skipjack resource is essentially untapped around Hawaii.

State of Hawaii fishery development activities continued throughout the 1980's[23], although the emphasis began to shift to "recreational" development (such as the deployment of fish aggregating devices [FAD's]) and to value-added seafood marketing (MacDonald et al., 1991). NMFS fishery development activity was increasingly directed through the Saltonstall-Kennedy grant process, and many of these funds were directed to other U.S.-associated areas in the western Pacific such as American Samoa, Guam, and the Northern Mariana Islands. The Saltonstall-Kennedy grant process also represented a privatization of development efforts in Hawaii, where most projects were carried out by individual fishing and seafood marketing companies.

Economic Research

Hudgins[24] surveyed economic research to date in Hawaii. Since then there has been a suite of studies directed toward fisheries management issues and seafood marketing. A substantial amount of this research has been funded by the Southwest Fisheries Science Center's regional economics program (Pooley et al.[25]). The following is a précis of economic research in which the Honolulu Laboratory was the principal investigator or a major collaborator.

Economic research directed toward fisheries management began with attempts to estimate the value of the recreational billfish fishery (Adams[26]) using household production models. An alternative methodology, primarily travel cost and contingent valuation, was attempted by Samples and SMS Research, Inc.[27] and Meyer[9], but funds have never been adequate to conduct full-scale socioeconomic surveys of the recreational and subsistence fisheries in Hawaii.

The most applied set of studies, however, has concentrated on detailed cost-earnings profiles of various fleets. Most productive of these studies was the analysis of the Northwestern Hawaiian Islands (NWHI) lobster fleet. Clarke and Pooley (1988) reported a detailed breakdown of lobster fishing economic profiles by class of vessel. Samples and Sproul[28, 29] and Gates and Samples[30], in work funded by the Western Pacific Regional Fishery Management Council, undertook a preliminary investigation of management alternatives for the NWHI lobster fishery. This was followed by a detailed bioeconomic model of the fishery by Clarke et al. (1992) which identified the relationship between the lobster resource and fleet dynamics.

In 1979–81, NMFS conducted some broad research surveys of the Hawaii seafood markets (NMFS[31]) which attempted to identify the important market channels (Cooper and Pooley[32, 33]). Further studies were conducted on the nature of competition in the seafood market (Adams[34], Pooley[35]). These studies generally concluded that the existence of auction markets and a high level of competition between fresh and frozen food distributors had been beneficial for market development in Hawaii. However, there has been little follow-up to the initial surveys in the subsequent ten years. Research on market dynamics has continued, however,

[23]Including an update of the fishery development plan (State of Hawaii, 1986) and the Hawaii Ocean Resources Management Plan (Hawaii Ocean and Marine Resources Council, 1991. Hawaii Ocean Resources Management Plan. Hawaii Dep. Business and Economic Development, Honolulu, Hawaii.).

[24]L. L. Hudgins. 1980. Economic analysis of Hawaii fisheries: a survey. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-80-07, 8 p.

[25]S. G. Pooley, S. F. Herrick, D. E. Squires, C. J. Thomsen, and G. W. Silverthorne. 1991. Southwest Fisheries Science Center and Southwest Region economics research plan, 1990-95. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-91-07, 20 p.

[26]M. F. Adams. 1978. Alternative estimate of net economic benefits for billfish-tuna recreational commercial fishermen in Kailua-Kona, Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-78-18, 10 p.

[27]K. C. Samples and SMS Research, Inc. 1983. Experimental valuation of recreational fishing in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-83-13C, 42 p.

[28]K. C. Samples and J. T. Sproul. 1987. Potential gains in fleet profitability from limiting entry into the Northwestern Hawaiian Island commercial lobster trap fishery. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-87- 17C, 30 p.

[29]K. C. Samples and J. T. Sproul. 1988. An economic appraisal of effort management alternatives for the Northwestern Hawaiian Islands commercial lobster fishery. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-88-12C.

[30]P. D. Gates and K. C. Samples. 1986. Dynamics of fleet composition and vessel fishing patterns in the Northwestern Hawaiian Islands commercial lobster fishery: 1983-86. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-86-17C, 32 p.

[31]National Marine Fisheries Service. 1982. Preliminary results of a survey of wholesale fish dealers in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-82-14, 17 p.

[32]J. C. Cooper and S. G. Pooley. 1982. Total seafood volume in Hawaii's wholesale fish markets. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-82-15, 12 p.

[33]J. C. Cooper and S. G. Pooley. 1983. Characteristics of Hawaii's wholesale seafood market. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-83-22, 33 p.

[34]M. F. Adams. 1981. Competition and market structure in the Hawaii fish industry. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-81-05, 20 p.

[35]S. G. Pooley. 1986. Competitive markets and bilateral exchange: the wholesale seafood market in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-86-08, 14 p.

with data derived from systematic monitoring of the primary wholesale markets. Whereas results on the dynamics of the bottomfish market showed a strong relationship between quantity supplied and price, thus identifying the demand function (Pooley, 1987a), results from the more wide-ranging tuna markets were less robust because of either inadequacies in the data or substantial discontinuities in the market (Pooley[36, 37]). Work was also conducted by the Council in collaboration with NMFS on the marketing dynamics of the lobster fishery (Samples and Gates[38]).

Economic research with a development slant was conducted on the future of the Hawaii skipjack tuna cannery which closed in 1984. NMFS sponsored an industry and academic workshop on factors affecting the supply and market of skipjack tuna (Boggs and Pooley[39], 1987; Pooley, 1987b). This work supplemented earlier research on the supply function for domestic tuna production in Hawaii (Hudgins, 1980) and subsequent research on the future for tuna fisheries in the western Pacific (Hudgins and Pooley, 1987). The gist of the workshop was that while a substantial tuna resource (primarily skipjack tuna) existed which could be exploited, the dynamics of the international canned tuna market would probably preclude reestablishment of the pole-and-line aku fishery in Hawaii for the foreseeable future (King[40], 1987). Emphasis has instead been on export of fresh bigeye and yellowfin tuna. Research was also conducted on the nature of the skipjack tuna as a discrete economic product, with identification of price vectors based on the size of fish (Hudgins[41], 1987), and there was marketing research conducted on extending the shelf-life of skipjack tuna (Hawaii Department of Business and Economic Development, 1989). Finally, there is an additional economic value of longline fishing to Hawaii, but this is from the port visits of foreign fishing and reefer vessels which operate throughout the mid-Pacific region (outside the U.S. EEZ's). Hudgins and Iversen[42] estimate the value of these visits at $46 million based on 2,500 port calls.

Finally, several collaborative economic studies were carried out by NMFS on behalf of the Corps of Engineers concerning small-boat fishing from the islands of Hawaii (Pooley[43]), Maui (Pooley[44]) and Oahu (Pooley[45]) These studies emphasized applying prototypical cost-earnings results from each fishery to estimate the net economic benefits of alternative fishery development schemes[46].

Fishery Management

Most of Hawaii's offshore marine fisheries are now under some form of Federal regulation through the Western Pacific Regional Fishery Management Council (Council). The basic premise of management under the Council for the NWHI lobster fishery and for the precious coral fishery has been to avoid biological overfishing. For the NWHI bottomfish fishery, avoidance of economic overfishing has been the primary motivation. In the MHI bottomfish fishery, primary concern has been on biological overfishing. Finally, the pelagic fishery (troll, handline, and longline gears used for catching tunas, billfish, and other ocean-dwelling pelagics) has been regulated essentially to avoid gear conflicts and other negative interactions between the growing longline fleet (targeting swordfish and tuna) and the smaller-scale troll and handline fleets (targeting tunas and billfish) (Pooley, 1990). However, the longline fleet was also excluded from areas around the NWHI to avoid interaction with endangered species, in particular the Hawaiian monk seal.

Despite the detailed cost-earnings and bioeconomic modeling of the NWHI lobster fishery, the limited entry program for NWHI lobster which was initiated in 1991 was based more on pragmatic grounds than on economic research per se. The limited entry program for bottomfishing in the NWHI was supported more directly by Council economic research in collaboration with NMFS (Meyer[9]) which attempted to identify the kinds of constraints facing the domestic fishing fleet. This work was not fully developed in terms of quantifying the pa-

[36]S. G. Pooley. 1990. Pelagic species prices in 1987-88. Southwest Fisheries Center, Honolulu Laboratory manuscript MRF-002-90H.

[37]S. G. Pooley. 1991. Revised market analysis: Hawaii yellowfin tuna. Southwest Fisheries Science Center, Honolulu Laboratory manuscript 003-091H-MRF.

[38]K. C. Samples and P. D. Gates. 1987. Market situation and outlook for Northwestern Hawaiian Islands spiny and slipper lobsters. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-87-4C, 33 p.

[39]C. H. Boggs and S. G. Pooley. 1987. Strategic planning for Hawaii's aku industry. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-87-01, 15 p.

[40]D. M. King. 1986. Global tuna markets and Hawaii aku. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-86-12C, 15 p.

[41]L. L. Hudgins. 1986. Economic issues of the size distribution of fish caught in the Hawaiian skipjack tuna fishery, 1964-82. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-86-14, 16 p.

[42]L. L. Hudgins and R. T. B. Iversen. 1990. Foreign flag fishing vessel expenditures in the Port of Honolulu, 1986–88. Report prepared for the State of Hawaii, Dep. Business, Economic Development and Tourism, Honolulu, Hawaii.

[43]East Hawaii commercial fishing mooring/launching facility project: economic and resources analysis. Southwest Fisheries Sci. Center, Honolulu Laboratory manuscript MRF-006-89H, report prepared for the U.S. Army Engineer Division, Pacific Ocean.

[44]Kahului small fishing boat facility: alternative net benefit estimates. Southwest Fisheries Sci. Center, Honolulu Laboratory manuscript MRF-004-89H, report prepared for the U.S. Army Engineer Division, Pacific Ocean.

[45]Report on Oahu small boat harbor fishery potential—Heeia Kea and Maunalua Bay. Southwest Fisheries Sci. Center, Honolulu Laboratory manuscript MRF-005-89H, report prepared for the U.S. Army Engineer Division, Pacific Ocean.

[46]Similar survey work was conducted for American Samoa, Guam, and the Northern Mariana Islands in cooperation with the island fishery agencies (L. D. Kasaoka. 1989. Summary of small boat economic surveys from American Samoa, Guam, and the Northern Mariana Islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-89-4C, 47 p.). However development of cost-earnings profiles was not completed due to lack of research resources.

rameters, but Pooley and Kawamoto[47] developed a series of cost-earnings profiles of the NWHI bottom fishing fleet which have been used in Council determinations on potential new entry into the fishery.

The limited entry regimes for NWHI bottomfish and lobster are both based on break-even levels of fishing effort at maximum sustainable yield. However, there has been relatively little interest in actually optimizing these fisheries. Where the biological dynamics of these fisheries are not well understood, and where the economics of fleet behavior between fisheries are quite fluid, these regimes may be considered quite appropriately as second-best optima under the circumstances.

Attempts at constructing linear programming models of the NWHI fishery (both as a directed bottomfish fishery and as a multipurpose fishery) were not particularly successful, but some experiments have been undertaken to model the components of fishing vessel operator behavior (Miklius and Leung[48]). This represents a novel approach to modeling decision processes and is based on detailed examination of vessel owner and captain incentives.

Although a considerable part of the pelagic fishery management problem revolves around allocation issues between segments of the fishery, information for fully developed economic models has been inadequate. The economic research mentioned in the description of Hawaii's recreational and subsistence fisheries, as well as the collaborative Corps of Engineers surveys, has been useful for fishery management purposes. Qualitative information was provided in the regulatory impact analysis of one amendment to the Pelagic Species Fishery Management Plan[49], but considerably more research is required.

Finally, although almost all of this research has revolved around Hawaii and has been directly economic in orientation, other pieces of social science research have been quite productive. Perhaps the most promising was the application of political bargaining models to the potential of management of South Pacific albacore (Schug, In press). This model looked at the constituent elements to successful negotiations and evaluated the conditions in that fishery during the conflict over drift-net fishing. The work is being extended to the current era when drift-net fishing has ceased.

Central Economic Issues

From one perspective, the central economic issues in Hawaii's marine fisheries are fairly simple. Because of the geographical isolation of Hawaii from other U.S. fishing fleets and because of the vastness of the central and western Pacific, as well as the distances and costs involved in fishing the NWHI, the large-scale commercial fisheries have tended to "manage themselves" to a certain extent. The regulatory structures at both a biological and economic level have been relatively simple, and interactions between fisheries are limited. On the other hand, since most of these fisheries have just completed their development stage, relatively little information is available on them, and both formal and informal management institutions, including associations of fishing participants, are even younger. Therefore each regulatory action is taken with a high degree of uncertainty concerning its effect on the participants in the fisheries and those associated with the fisheries[50].

A good example has been the recent closure of waters around the main Hawaiian Islands to longline fishing. The closures were designed to reduce gear interactions between the longline fleet on the one hand and troll and handline boats on the other, while still allowing the longline fleet access to the remainder of the waters around Hawaii. At the time, a considerable portion of the fleet was traveling as much as 1,200 miles from Honolulu, but two segments of the longline fleet were adversely affected. It was anticipated that the smaller wooden and fiberglass longline sampans would be affected, and provision to allow them exemptions to fish in their customary waters inside the closure was recommended.[51] It was not anticipated that a substantial portion of the remaining portion of the fleet, as many as 30–40 modern longline vessels, would choose to tie-up rather than fish outside the closure area. (The reasons for this are not yet clear.) Furthermore, although there was a presumption that the closures would be a de facto allocation in favor of the commercial troll and handline boats, their landings apparently did not rise during the period. The resulting impact of reduced landings on the local seafood market for tuna and other pelagics was substantial during the summer and fall of 1991, and a number of dealers also indicated economic hardship as a result of the closures.

This leads to the central economic issue in Hawaii's marine fisheries: the allocation of uncertain quantities of fish (primarily tunas and pelagics but also bottomfish) between the larger-scale commercial fishing fleets and the smaller-scale commercial, part-time commercial, subsistence, and recreational fishing boats. The subject may be intensified by native Hawaiian claims to preference in some of these fisheries (Iversen et al.[13]), but research on these issues is primarily in the purview of the Council and the State of Hawaii's Office of Hawaiian Affairs.

Biologically, a commercially caught fish is pretty much the same as a recreationally caught fish in Hawaii,

[47]S. G. Pooley and K. E. Kawamoto. 1990. Economic analysis of bottomfish fishing vessels operating in the Northwestern Hawaiian Islands, 1984-88. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-90-13, 21 p.

[48]W. Miklius and P. S. Leung. 1990. Behavior modeling in the multi-fishery: an evaluation of alternative methods. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Honolulu Lab., Southwest Fish. Sci. Cent. Admin. Rep. H-90-11C, 13 p.

[49]Proposed regulatory impact review: Amendment 4: Pelagic Fisheries FMP. Southwest Fisheries Science Center, Honolulu Laboratory manuscript 005-91H-MRF.

[50]This is true of many mainland U.S. fisheries as well. The difference is the very short time-series of information on which to base resource and economic assessments in Hawaii.

[51]As it turned out, only a few of these vessels met the stringent qualifying criteria.

although there are some size composition differences. U.S. fishery management history tended to favor domestic commercial fisheries until the late 1980's, with the pendulum now tending to swing more towards conservation and towards recreational and small-scale commercial interests. That has certainly been the case in Hawaii's pelagic fishery interaction issue. On the other hand, in the MHI bottomfish case, conservation has clashed substantially with recreational, subsistence, and small-scale commercial interests, with a large presumption going toward access, rather than conservation.

From one point of view, the political pluralism of the MFCMA fishery management system is an appropriate balancing of these concerns. Not only are there representatives of different fishing interests on the Council, there is also direct representation from different levels of government. Furthermore, at least in Hawaii, there is relatively easy access to the Council process, including a quite vocal and frequently educational public hearing process. On the other hand, some people fear that the decision-making process has not had or used enough information on the relative benefits and costs to the various human components of the fisheries. Weighing the market value of a commercially caught fish in terms of its income and employment generating impact against the nonmarket value of a recreationally caught fish in terms of enjoyment and personal consumption is hard enough. This is made more difficult by monetized and nonmonetary "rights" to fishing access and the probability that reducing large-scale commercial fishing probably will not generate an equivalent volume of landings (in weight or numbers) through the alternative fisheries. Then, the question becomes one of evaluating the marginal impact of fishing regulations on multiple interest groups. Furthermore, as contentious as the marine fisheries issues have been, a much more contentious set of marine resource issues faces Hawaii legislators and resource managers: the alternative uses of the near-shore and coastal environment (Hawaii Ocean and Marine Resources Council[52]). In Hawaii, we are nowhere near making such determinations.

Conclusion

What can economic and social science research contribute to the weighing of benefits and costs from development and conservation in Hawaii's marine fisheries? The answer to this question lies in the nature of the regulatory process.

Fisheries management, as codified by the MFCMA and various Federal rules, is a political process dominated by strategic bargaining on the part of its participating interest groups. As such, it is a classic example of political pluralism at the margin within tightly structured political boundaries and loosely structured economic and social systems. This political process contrasts strongly with three important presumptions in the MFCMA process:

1) Regulatory legalism,
2) Scientific rationalism, and
3) Laissez-faire economic ideology.

Clearly, in addition, there is a strong natural science presumption to issues of fisheries management, even though it is now commonplace to acknowledge that it is the people who participate in the fishery, from the harvesters to the dealers who are managed, not fish. Although participants in the fisheries management process know parts of this regulatory landscape, there is very little systematic knowledge of these basic contradictions.

Probably the most important potential contribution of social science research would be toward understanding the behavior of individuals and groups in the fishing community, particularly in terms of understanding changes in human behavior due to regulation (ex ante and contrapositive), endogenous changes in fishing technology, and exogenous events such as changes in alternative labor markets, changes in oil prices, or changes in ocean and coastal zone use. This requires a fact-based, micro approach to social science research, not abstract models of fishing behavior. Unfortunately, although this kind of research promises important contributions to fisheries management decisions, neither its time frame nor its research resource requirements correspond to the short-term agendas of fisheries management bodies.

In Hawaii this should suggest two new approaches. First, there should be a wider scope for fisheries economics research to include a range of marine resource use issues as well as coastal zone and environmental economic issues. Second, this research should include a wider collaboration between university, state, and Federal researchers in a number of agencies, and probably a greater explicit collaboration with fishing (and similar user group) communities in the conduct of economic research. These approaches would take substantial new research resources, but they remain trivial compared to the overall cost of natural science research in fisheries and the social opportunity costs of overharvesting.

[52]Hawaii Ocean and Marine Resources Council. 1991. Hawaii Ocean Resources Management Plan. Hawaii Dep. Business and Economic Development, Honolulu, Hawaii.

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The Western Pacific Fishery Information Network: A Fisheries Information System

DAVID C. HAMM

Introduction

Fisheries in the Pacific have been rapidly changing during the 1980's, and fisheries agencies have been changing with them to obtain and utilize the proper data and information needed to monitor and manage the resources under their jurisdictions. To help meet the ever growing and changing information needs of fishery agencies of the Pacific, the National Marine Fisheries Service (NMFS) established a Pacific Fishery Information Network (PACFIN) for the western coastal states and Idaho, and the Western Pacific Fishery Information Network (WPACFIN) for the U.S.-affiliated fishery agencies in the central and western Pacific island areas of American Samoa, Hawaii, Guam, and the Northern Mariana Islands. This paper is exclusively concerned with WPACFIN.

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ABSTRACT—The Western Pacific Fishery Information Network (WPACFIN) is an intergovernmental agency cooperative program sponsored by the National Marine Fisheries Service (NMFS) to help participating island fisheries agencies carry out data collection, analysis, reporting programs, and data management activities to better support fisheries management under the Magnuson Fishery Conservation and Management Act; and to help meet local fisheries information and management needs. The WPACFIN is the central source of information for Federal fisheries management of most fisheries in American Samoa, Guam, and the Northern Mariana Islands, and it plays an important role in acquiring fisheries data in Hawaii. This paper describes the development and status of this fishery information system.

Through the NMFS WPACFIN program, an organization of cooperating island fisheries agencies has developed a network to share data, information, and technology to improve fisheries management under the Magnuson Fishery Conservation and Management Act and to meet local fisheries management needs. The voluntary and cooperative nature of the network cannot be overemphasized, for these attributes are the backbone of the existence of the system. The information available through WPACFIN has been developed through cooperative efforts of the participating agencies to improve their data collection, compilation, computerization, and summarization capabilities by means of technical assistance provided by the central WPACFIN program at the Honolulu Laboratory and by means of financial assistance from various NMFS and other funding sources.

From the beginning, it has been the philosophy and policy of the WPACFIN program to adopt the general NMFS policy of building upon local fisheries office expertise and capabilities as a means of improving Federal fishery management capabilities. The WPACFIN system embodies the general principles of a Federal and state partnership and a symbiotic relationship in collecting, processing, analyzing, sharing, and managing fisheries data, and builds upon the history of cooperation among agencies. From the standpoint of the NMFS, the overall functional goal of the WPACFIN system is to provide quality fisheries data needed to develop, implement, evaluate, and amend Federal fishery management plans (FMP's) for the western Pacific region. The information needed to manage Federal fisheries under MFCMA should be a composite subset of information required by fully functional local fisheries agencies. Therefore, the operating philosophy of the central WPACFIN office in working with island agencies has been to assist them in becoming fully functional in obtaining and providing data and information needed to meet both Federal and local fishery management needs. By building upon the capabilities of local agencies, efficiency, benefits, functionality, and data availability can be maximized while overall costs and duplication of effort can be minimized. Accomplishing this requires significant levels of commitment on both sides and a common goal for improved fisheries management.

The WPACFIN system

The use of the term WPACFIN is sometimes confusing because it can be used to refer to any of the three distinct but interrelated major aspects of the system that are embodied in the concept of a cooperative fishery information network, or it can refer to the "system" as a whole. The three aspects of the WPACFIN system are its 1) organization, 2) program, and 3) network. These are all intertwined and inseparable as far as the functionality of the WPACFIN system is concerned.

The WPACFIN organization refers to the combination of participating agencies and how they interact to make

decisions and recommendations for improving fishery management capabilities in the region. The participating agencies of WPACFIN (Fig. 1) include the Western Pacific Regional Fishery Management Council (WPRFMC or Council), the American Samoa Department of Marine and Wildlife Resources (DMWR), the Commonwealth of the Northern Mariana Islands' Division of Fish and Wildlife (DFW), the Guam Division of Aquatic and Wildlife Resources (DAWR) and Department of Commerce (DOC), the Hawaii Division of Aquatic Resources (HDAR), and the Honolulu Laboratory and Pacific Area Office of the NMFS. For simplicity, this paper will refer to the island fisheries offices not based in Hawaii as the "flag state" agencies.

To help coordinate all the participating agencies and to help set goals and priorities for meeting the information needs through WPACFIN, a committee composed of all the heads of the participating fisheries agencies was established in 1982. This committee was originally named the WPACFIN Data Goals Committee, but was later renamed the WPACFIN Fisheries Data Coordinating Committee (FDCC). The FDCC is the advisory body within the WPACFIN organization. The intent of the committee is to ensure that all required data are available to each participating agency and to the Western Pacific Regional Fishery Management Council, its Plan Monitoring Teams, its Scientific and Statistical Committee, and fishery managers, in a form, quality, and time frame necessary to meet their respective fisheries management responsibilities. Specifically stated, the purposes of the WPACFIN FDCC are to:

1) Provide a forum for a regional exchange of ideas about fisheries data and for meeting local and regional fishery management goals;

2) Establish WPACFIN activities and priorities and recommend improvements in efficiency, effectiveness, and timeliness of data collecting and processing activities;

3) Develop and coordinate a WPACFIN Fisheries Data Plan for implementation in each member area;

4) Promote the development and implementation of data collection, storage, and transfer standards to facilitate merging data into WPACFIN; and

5) Designate membership of a Technical Subcommittee and coordinate the Subcommittee's work on technical aspects of implementing WPACFIN.

The FDCC also established guidelines for the proper exchange and use

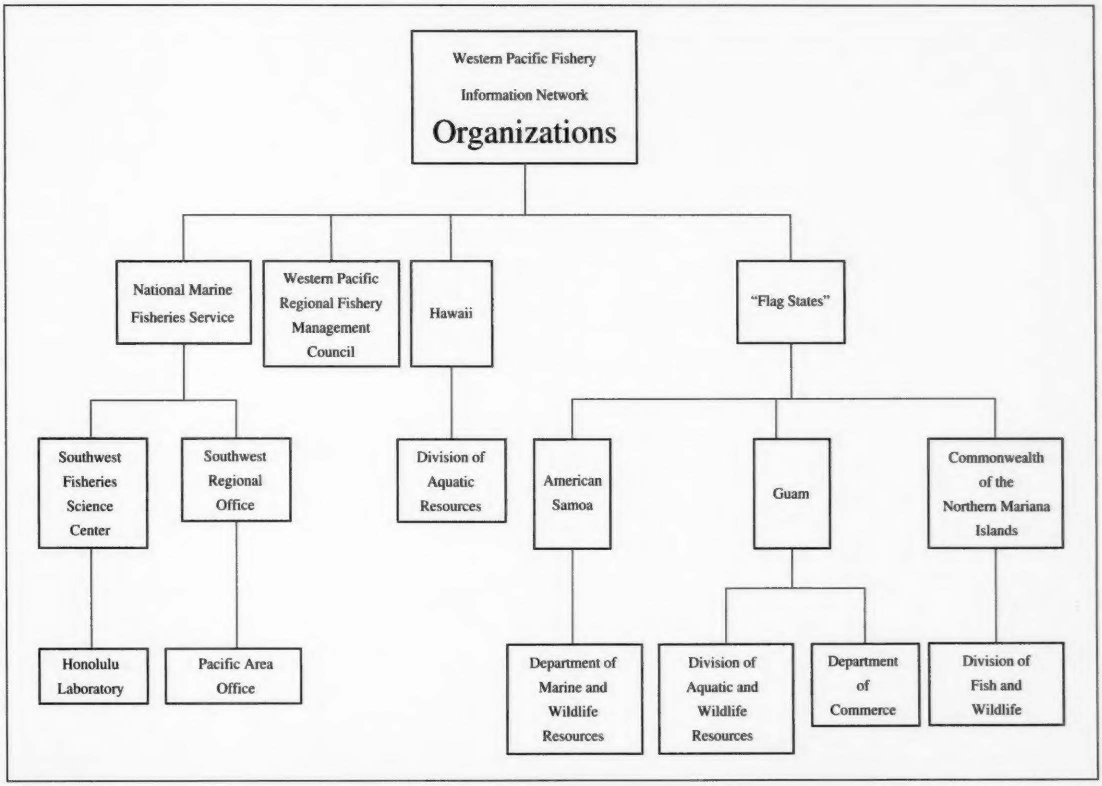

Figure 1.—Organizations participating in the Western Pacific Fishery Information Network.

of fishery data and for safeguarding the confidentiality of data submitted by member agencies:

1) WPACFIN will not release confidential data in any format without specific written permission from the agency contributing the data to the system.

2) Requests for raw (nonsummary) data or requests from nonmember agencies will be referred to the donor agency.

3) If access is granted by the donor agency, WPACFIN may provide the data directly to the user from the central system at the donor agency's request.

4) Confidential data submitted to WPACFIN are generally available for NMFS employees to use provided the employee has signed a Statement of Nondisclosure and has a "need-to-know" as defined in NOAA Directive 88–30.

5) Summary and nonconfidential data in WPACFIN are available to all users without obtaining donor agency approval.

6) Specific restrictions may be placed on sensitive data sets submitted to WPACFIN that could limit access to users identified by the donor agency.

The WPACFIN program is a task within the Fishery Data Management Program of the NMFS Honolulu Laboratory's Fishery Management and Performance Investigation. It was established in 1981 to be the nucleus for organizing, implementing, and maintaining the fisheries information network in the western Pacific. The WPACFIN program is headed by the leader of the Fishery Data Management Program, and its staff has expertise in computer systems design, fisheries biology, and computer programming. The types of support offered by the WPACFIN program cover a variety of administrative and technical activities. Because of differences in data collecting and processing systems, political atmosphere, personnel, and level of commitment to upgrade and change, the flag state agencies have been the major focus of implementing the WPACFIN system, and they have been the major users of support offered by the WPACFIN program. Description of some of the major WPACFIN program support activities follows.

1) Administrative support has been provided at all levels for overseeing the WPACFIN program management, budgeting, and planning activities, such as developing and implementing "memoranda of understanding" and data sharing agreements between NMFS and participating agencies, and coordinating meetings of the FDCC and its Technical Subcommittee.

2) Technical hardware and software support has been crucial to developing local expertise.

3) System and survey designs have been studied in all areas, either by using consultant contracts or in-house NMFS expertise and resources (CIC Research, Inc.[1, 2], Omnitrak Research and Marketing Group, Inc.[3], and Malvestuto[4]).

4) Data base management and data processing systems have been established for many data systems such as commercial landings, offshore and inshore creel surveys, tuna transshipment, tournament sampling, vessel inventory, and fishery imports. Integrated, menu-driven, user-friendly, data base management systems have been developed and programmed to meet the needs of island agencies.

5) A wide range of training support has been provided to island agencies including on-site and central training workshops on microcomputer hardware and software, data base and file management, data quality control procedures, data collecting, forms design, and detailed training on implementing the data processing applications.

6) Fisheries data bases provided to the system by participating agencies are maintained at the central WPACFIN program office. Direct on-line access to some of these centralized data bases is a long-range goal.

7) Numerous report generation and data analysis activities, such as filling ad-hoc data requests, assisting in producing the flag state agencies' report modules for the annual bottomfish and pelagics plan monitoring teams (Hamm and Quach[5]; Hamm et al.[6, 7]), and producing the annual catch and effort report series "Fishery Statistics of the Western Pacific" (Hamm et al., var. years[8]).

In addition to providing these support functions to the official WPACFIN agencies, the central WPACFIN program office has provided similar technical guidance and assistance to fisheries offices in other U.S. affiliated Pacific island areas such as the Federated States of Micronesia (Pohnpei, Kosrae, Chuuk, and Yap) and the Republic of Palau, but on a more limited basis. Notwithstanding the limited support provided, at least some "WPACFIN-compatible" data systems have been created in each of these other island areas.

The WPACFIN network refers to the technologies, activities, and meth-

[1]CIC Research, Inc. 1983. A fishery data collection system: Guam. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-83-21C, 85 p.

[2]CIC Research, Inc. 1983. A fishery data collection system: Saipan. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-83-20C, 74 p.

[3]Omnitrak Research and Marketing Group, Inc. 1988. Sampling methodology for a boat fishing survey design for Hawaii. Honolulu, HI 96813, 173 p.

[4]Malvestuto, S. P. 1991. Recommendations for statistical treatment of Hawaii small boat survey data. Fishery Information Management Systems, Auburn, AL 36830, 6 p.

[5]Hamm, D. C., and M. M. C. Quach. 1988. Bottomfish fisheries of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-88-15, 76 p.

[6]Hamm, D. C., M. M. C. Quach, R. Tokunaga, F. Aitaoto, G. W. Davis, and T. J. Donaldson. 1989. Review of the 1988 pelagic fisheries of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-89-7, 101 p.

[7]Hamm, D. C., M. M. C. Quach, F. Aitaoto, G. W. Davis, and T. J. Donaldson. 1989. Review of the 1988 bottomfish fisheries of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-89-8, 83 p.

[8]Hamm, D. C. et. al. 1986 Vol. I, 1986 Vol. II, 1988 Vol. III, 1989 Vol. IV, 1990 Vol. V, 1991 Vol VI, and 1992 Vol VII. Fishery Statistics of the Western Pacific. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-86-4, 380 p., Admin. Rep. H-86-20, 237 p., Admin. Rep. H-88-4, 352 p., Admin. Rep. H-89-1, 216 p., Admin. Rep. H-90-09, 224 p., Admin. Rep. H-91-1, 230 p., Admin. Rep. H-92-06, 230 p.

odologies upon which the system functions, including all the hardware, software, communication links, data sharing capabilities, and the data bases themselves. The network is the backbone of WPACFIN, and is a physical part of each participating agency. In general, the network is a microcomputer-based means of sharing data and information among fisheries agencies to support fisheries management needs via mail and direct telecommunications. It is more fully described under the WPACFIN evolution section of this paper.

Together, these three aspects of WPACFIN, the organization, program, and network, make the WPACFIN system what it is, a combination of agencies working together in a voluntary and cooperative manner to improve fishery management capabilities in the central and western Pacific region.

Problems and Challenges of Implementing WPACFIN

Implementing an information network among the U.S. affiliated islands of the Pacific required resolving some challenging problems and operating within certain strict limitations. Effective communication is important in any cooperative undertaking, but it is critical in a task such as developing and implementing WPACFIN. The first, and possibly most obvious obstacle limiting communication among participating agencies is the physical size of the area involved. The distances between the central WPACFIN office and the flag state agencies are great, and the Exclusive Economic Zones (EEZ's) are the largest under jurisdiction of any of the Councils, totaling over two million square miles (Fig. 2). To put the size of the area in perspective, if the central WPACFIN office was in Bangor, Maine, the American Samoa fisheries office would be in Venezuela and the Guam and Saipan offices would still be in the Pacific Ocean well west of California. The distances make costs of on-site visits high, and communication via telephone lines is also quite expensive; thus, overcoming the complications caused by the distances involved was no minor task, but progress was steadily made because of the high level of cooperation and commitment by the flag state agencies. On-site visits to the flag state agencies by central WPACFIN technical staff were well planned and always productive by concentrating a lot of activity into the few days available.

Cultural differences represent a second challenge in communication that is also somewhat related to the size of the area covered. The Samoan, Hawai-

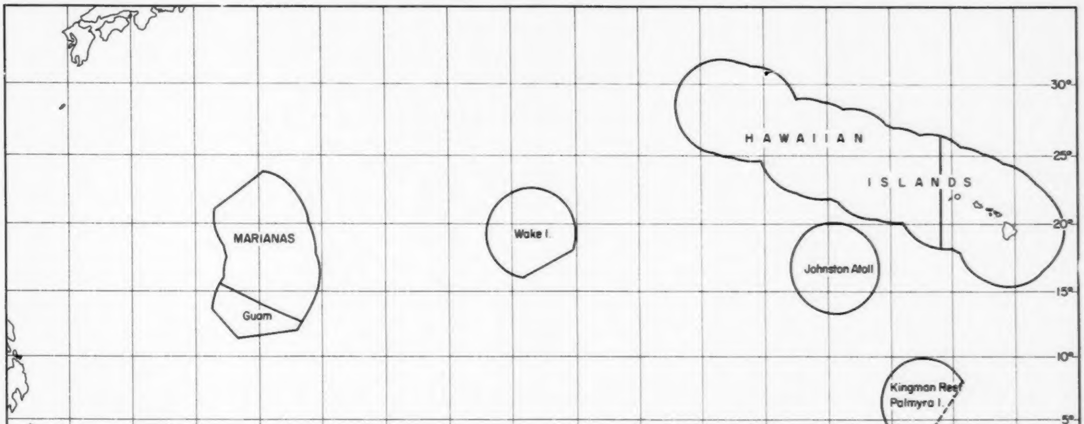

Figure 2.—Boundaries of the Fishery Conservation Zone around Hawaii, American Samoa, Guam, the Northern Mariana Islands, and other U.S. possessions.

ian, and Chamorro/Carolinian cultures are all quite different; even within the Chamorro/Carolinian cultures of Guam and the CNMI, differences exist between islands. Overcoming communication problems and understanding limitations related to cultural differences require sensitivity to and respect for local customs, preferences, inhibitions, attitudes, and sometimes underlying and significant prejudices. It requires time to build relationships, gain confidences, and understand the differences and nuances of each island culture. Not understanding or ignoring cultural differences reduces the effectiveness of communication and is likely to result in less functional and useful data systems. The WPACFIN philosophy embodies these cultural differences as much as possible in developing new or modifying existing data systems. Related to the cultural differences are political differences and stages of development of the bureaucracies of the island fisheries agencies; these too must be considered and overcome.

Several other complications in developing an automated fishery information network in the Pacific may be broadly categorized as infrastructure problems. In 1981, only the State of Hawaii possessed laws requiring the reporting of fisheries statistics. Therefore, historical data for the early years of most island fisheries were inadequate, as was available funding; voluntary reprogramming of available funds by the flag state agencies made implementing data system changes possible. Progress was also hindered by a lack of adequate staff. Fisheries and computer professionals are still very scarce in the Pacific, so the central WPACFIN office has had to provide nearly all computer training and programming support, at least to the flag state agencies. The American Samoa and CNMI offices rely almost exclusively on contract professional biologists from the U.S. mainland. As a result, a high level of turnover, low level of stability in programs, and a poor understanding of the history of the fisheries exist. The WPACFIN program has worked to help the island agencies overcome these problems.

The last noteworthy challenge in implementing and upgrading WPACFIN has been the dynamics of rapid changes in the fisheries, the data needs, and the computer technologies over the past decade. In the early years, fisheries managers required only a few summary tables and enough basic data to categorize the fisheries and document their importance for justifying and implementing fishery management plans. Now, more detailed annual reports are required that document status of the stocks aspects of fishery performance, and selected economic indicators. Fortunately, computer technology capable of handling the increased data and analytical needs has also expanded, but with the expansion has come a challenge of maintaining stability of systems while implementing significant improvements. This has been accomplished successfully in the flag state agencies where levels of cooperation were high and levels of bureaucracy and changes in the basic fisheries were fairly low, but less successfully in Hawaii where the reverse is true.

WPACFIN Evolution

The discussion of the evolution of the WPACFIN system will be divided into the same three aspects of WPACFIN as previously described, the organization, program, and network.

The original members of the WPACFIN organization included all those shown in Figure 1, except the Guam Department of Commerce, which joined in August 1988. Initially, HDAR participation in the FDCC was self-limited to observer status, but in December 1984, with completion of the Hawaii statistical system study (DLNR[9]), they became a full voting member of the FDCC. The FDCC held ten meetings from 1982 to 1989 which mostly dealt with issues such as establishing memoranda of understanding and data share agreements, developing guidelines for operating the FDCC, implementing the first and second generation systems, and seeking additional funding to support the network. From 1989 to 1992, the FDCC met eight more times and concentrated its efforts on defining projects and objectives under the new PACFIN initiative, developing a long-term data plan for the Pacific, and redefining the functions, services, and data bases the future WPACFIN system should include. The FDCC's Technical Subcommittee has held several workshops and training sessions and has developed standard guidelines for data quality control and file management procedures to be used by each member agency in developing their own specific procedures to insure that only quality data enter the central WPACFIN files.

The WPACFIN program has been crucial to WPACFIN system development. Established in 1981 by the Southwest Fisheries Center as a separate task within the Honolulu Laboratory, it was initially staffed with one full-time computer systems analyst. Staff size and expertise expanded to improve WPACFIN capabilities in meeting overall fishery information and Council-related needs. Expertise in fisheries biology was transferred into WPACFIN to help with fisheries applications and analyses.

Discussion of the evolution of the WPACFIN network will be limited to the major hardware and software used and will be described in three sections, pre-WPACFIN, first generation WPACFIN, and second generation WPACFIN. Identification of the data bases maintained within the network is found in the next section.

The pre-WPACFIN situation was a fairly unstructured, low technology environment involving no computer use outside Hawaii. Fishery statistics in the flag states were computed by hand or sometimes with the use of desktop calculators. Data collecting systems, where they existed, were fairly rudimentary and typically were not based on valid statistical designs. Data processing at HDAR and the Honolulu Laboratory was performed by keypunch cards, batch processing, and limited time-share processing on state-operated IBM mainframe computers. Data exchanges were limited to periodic

[9]Div. Aquatic Resources, State of Hawaii. 1984. Hawaii fisheries statistics system design study. Division of Aquatic Resources, Div. Land and Natl. Resources, 214 p.

transfer of computer tapes from HDAR to the Honolulu Laboratory. The HDAR had over a two-year backlog of data to process.

The initial steps in implementing the first-generation WPACFIN system consisted of installing a two-station, key-to-disk data entry system at the Honolulu Laboratory and Apple II+ microcomputer systems in each of the original four participating island agency main offices plus central WPACFIN. These Apples were the first microcomputers introduced into any of the flag state agencies. The original off-the-shelf software included a highly structured, but somewhat limited, data base management system capable of all processing steps from data entry through report generation, a spreadsheet system, some rudimentary graphics and statistics packages, word processing, and some basic utilities. By the end of 1982 all island systems had been installed, basic training provided, and data bases established for the major fishery monitoring systems (Hamm[10]). Over the next several years, hardware and software upgrades continued to be made which included additional computers, networked hard drive units in two offices, and extensive custom-programmed processing systems for newly designed and implemented creel survey sampling programs in all flag state areas (Hamm[11]). Additional data bases and improved sampling programs were established in all flag state areas to monitor the resources better. The HDAR began reducing the backlog of landings reports and completed the WPACFIN-funded "Hawaii fisheries statistics system design study" (1984). Some of the newly designed sampling programs for the flag states (e.g., market sampling, size frequency and biological sampling, some creel surveys) were never implemented or were soon terminated because of lack of funds to conduct the work or because of a lack of demonstrated and reinforced need for these data for federal management purposes. This proved to be most unfortunate as these types of baseline data were later needed by Council Plan Monitoring Teams.

In addition to the Apple II+ hardware for processing centrally stored files, the first generation central WPACFIN hardware environment initially included a time-share link to a PDP 1170 minicomputer. However, the availability of the minicomputer proved to be short-lived, and the Laboratory obtained an in-house CPM-based multiuser-multiprocessor super-microcomputer with over 40 workstations which became the central computer for some WPACFIN applications. This fairly simple first-generation processing environment continued to meet data processing needs into the mid-1980's when it became apparent that a major switch to more modern and powerful processing equipment would soon be needed to meet the ever increasing federal requirements for more sophisticated analysis and reporting.

The evolution to second-generation WPACFIN processing systems began with the microcomputer boom of the mid-1980's.

Whereas most of the first-generation hardware and software systems were provided through central WPACFIN technical and financial support, the evolution to second-generation WPACFIN processing systems required much more financial commitment from the other participating agencies. This was partly accomplished through reprogramming existing Federal grant funds which had already been extensively used to implement improvements in data collecting systems, and partly through the use of other Federal and local funds. The new WPACFIN standard operating environment centered around the IBM-compatible MS-DOS microcomputer and the dBASE data base management system. The microcomputer revolution soon reached all participating agencies, and they began expanding their use of computers beyond their fisheries data sections to their fisheries biologists, and wildlife and administrative sections. The American Samoa DMWR, CNMI DFW, and Guam DOC offices followed the WPACFIN standard almost exclusively in their expansion efforts, but the Guam DAWR office chose to use the Apple Macintosh system and the HDAR office expanded in several directions simultaneously: into direct use of the IBM mainframe, a newly installed State WANGNET minicomputer system, and into increased use of both Macintosh and IBM-compatible microcomputers.

During the evolution to second-generation computer systems, the major emphasis of the central WPACFIN program was to support the conversion to the new IBM-compatible operating environment by assisting with purchases of hardware and software and by developing much more sophisticated and comprehensive, user-friendly, menu-driven dBASE applications for an increasing number of data collection and analysis systems. The most recent phases of implementing the second generation WPACFIN system include establishing direct computer-to-computer telecommunications links between the central office and all other agencies, and creating an on-line central system for dial-in access to principal island data sets. The evolution into the second-generation operating environment is continuing. As all the basic fisheries data systems become fully functional in the new operating environment, more emphasis will be placed on developing more integrated data systems and additional analysis, assessment, and reporting systems to enhance fisheries monitoring and management.

Current Data Systems

NMFS and each of the four island areas have a variety of data bases and associated collecting and processing systems to facilitate fisheries monitoring and management activities (Table 1), but it is beyond the scope of this paper to document them fully. Each fishery, island agency, and data processing system has its own needs, pe-

[10]Hamm, D. C. 1982. Preliminary description of the Western Pacific Fishery Information Network. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-82-2, 11 p.

[11]Hamm, D. C. 1985. Western Pacific Fishery Information Network, organization and design, status and issues. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Southwest Fish. Cent. Admin. Rep. H-85-4, 35 p.

culiarities, uses, capabilities, and limitations that make it unique. In general, each agency is responsible for ensuring its data are as accurate as possible before sharing files through the central WPACFIN office. Most data collected by participating island agencies are centrally archived for ready access and data sharing in WPACFIN files at the Honolulu Laboratory. Most data collected by NMFS are maintained at the Honolulu Laboratory by the Fishery Management and Performance Investigation to reduce WPACFIN storage requirements. Not all data are readily available to all users because of confidentiality or sensitivity considerations, or because use of the data is local rather than regional.

From a fisheries monitoring perspective, the most important systems in each island area are the commercial landings, creel survey, and logbook systems. Even though these systems vary significantly in design and degree of implementation from island to island and from system to system (e.g., voluntary vs. mandatory, on-site vs. mail-in, census vs. sample, and local agency vs. central WPACFIN sponsored), they provide the basis for monitoring fisheries of the area. The other data systems operated by fisheries agencies provide important validation cross-checks, biological status, augmentary, and ancillary information on the resources and fisheries exploiting them.

Table 1.—Data collecting and processing systems.

System	NMFS	Samoa	Guam	CNMI	Hawaii
Commercial landings		X	X	X	X
Offshore "creel" surveys		X	X	X	X
Inshore "creel" surveys		X	X	X	
"Tuna" transshipment		X	X	X	
Vessel inventory		X	X	X	X
Tournament sampling		X	X	X	
Length/size sampling	X	X	X	X	
Biological sampling	X	X	X	X	
Permits and licenses	X	X	X	X	X
Imports and/or exports			X	X	
HI auction monitoring	X				X
NWHI lobster logbooks	X				
Longline logbooks	X				

Future Goals of the WPACFIN System

During the past 11 years, significant progress has been made toward meeting fisheries management needs in each of the Pacific island areas under the Council's jurisdiction; however, much more remains to be done. Fisheries management information requirements continue to change, and significant data and information gaps still exist. Filling those gaps will require some reorientation of major activities within the WPACFIN system to implement further improvements in the methods of data collection, processing, analysis, and reporting. Some of the goals of the WPACFIN system for future activities are the following:

1) Analyze existing data systems to document information gaps.

2) Establish additional data collecting, processing, and analyzing standards, and implement changes required to meet those standards.

3) Implement computer-based telecommunications between all participating agencies to facilitate data exchange and system upgrades.

4) Establish dial-in access to centrally archived data bases.

5) Establish integrated central data bases and create a sophisticated query system to improve access to and use of available data.

6) Develop new and improved fisheries assessment and analysis systems to increase the reliability of information used in the fishery management decision making process.

7) Encourage further state and Federal cooperative efforts in meeting fishery management objectives in the western Pacific.

Summary

Over the past 11 years the NMFS's WPACFIN program has assisted island fisheries agencies in advancing from nonexistent or rudimentary manual data systems to sophisticated computerized systems capable of providing useful fisheries monitoring and analysis information on a timely basis. Through the cooperative efforts of all participating agencies, the WPACFIN system has become the common thread that weaves the member agencies together through sharing data and information about the fisheries of the Pacific in their efforts to protect and manage these resources.

Several critical factors have been identified which influence the level of success obtainable in implementing a complex, intergovernmental, voluntary, and cooperative project such as this fishery information network:

1) Commitment and ability of agencies to implement changes and provide resources to accomplish change.

2) Long-term commitment and quality of individual employees involved in the project, especially those involved in project management.

3) Consideration of local needs, culture, politics, capabilities, limitations, and personnel.

4) Continual contact, support, feedback, and training.

As fisheries change and fisheries management needs grow in complexity and diversity, so must the resolve of the participating agencies grow to meet the new challenges. The most important factor influencing the future of the fisheries of the Pacific will continue to be the desire and the ability of the many agencies to work together to become a unified force in meeting the challenges of rational and effective fisheries management. It is the long-term goal of the WPACFIN system to assist in making effective management a reality. The WPACFIN system continues to evolve to meet needs of rapidly changing fisheries management requirements.

The Commercial, Subsistence, and Recreational Fisheries of American Samoa

PETER CRAIG, BONNIE PONWITH, FINI AITAOTO, and DAVID HAMM

Introduction

Many tropical islands in the South Pacific Ocean are confronted by rapidly growing human populations, but have few economic resources that their residents can utilize. Fish resources, from traditional subsistence fishing in times past to today's more modern boat-based fisheries, have always been an important component of island economies (Doulman and Kearney, 1991). It is therefore of interest to examine the current use and potential development of such fisheries. An overview of recent trends in the small, but locally important, domestic fisheries in American Samoa is presented in this paper. This includes four fisheries: 1) a shoreline subsistence fishery, 2) an artisanal fishery for offshore pelagic fishes, 3) an artisanal fishery for offshore bottomfish, and 4) a recreational tournament fishery. For completeness and contrast, the much larger distant-water fleet of commercial vessels that deliver tuna to canneries in American Samoa is also briefly described.

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ABSTRACT—Domestic fisheries in American Samoa landed 587,000 lb of fish and invertebrates in 1991 worth $993,000. Most of the catch (78%) and value (80%) was taken by the shoreline subsistence fishery that occurs on the coral reefs surrounding the islands. Artisanal fisheries for offshore pelagic fishes (primarily skipjack tuna, Katsuwonus pelamis*; and yellowfin tuna,* Thunnus albacares*) and bottomfishes (snappers, emperors, groupers) accounted for 16% and 3%, respectively, of the domestic catch. Recreational tournament catches for pelagic fishes represented the remainder (3%).*

While sport fishing is becoming increasingly important, other domestic fisheries have declined in recent years. The shoreline subsistence fishery has dropped by about 25% over the past decade owing to socioeconomic factors and possibly overexploitation. Artisanal fisheries have also declined precipitously in recent years owing to hurricane-related damages, attrition of fishermen, and competition with imports. Artisanal fisheries show some potential for growth, but may be constrained by marketing issues, vessel capabilities, and limited stock sizes (for bottomfish) or local availability of high-value (pelagic) fishes.

In contrast to the small-scale domestic fisheries, American Samoa is also homeport to a distant-water fleet of large purse seiners and longliners that fish beyond the EEZ and deliver about 160,000–220,000 short tons of tuna per year to local canneries.

Study Area

American Samoa, the only U.S. Territory in the southern hemisphere, consists of 7 small islands in the central South Pacific Ocean (Fig. 1). The largest islands are Tutuila and the Manu'a group (Ofu, Olesega, and Ta'u Islands). The total land area is only 77 mi.^{2}. Most of the islands have steep volcanic slopes with limited flat land suitable for human habitation or agriculture. The Territory's population (46,600 in 1990), located primarily on Tutuila Island, is growing rapidly (3.7% per year) and has a doubling time of only 19 years (EDPO, 1991). The two major employers are the tuna canneries and the local government, which employ 33% and 31% of the labor force, respectively. There is a heavy reliance on imports for food, fuel, and materials (EDPO, 1991). Canned tuna is the only significant export, which supplies about 25% of all canned tuna consumed in the United States.

Data Collection System

The Department of Marine and Wildlife Resources (DMWR) in American Samoa provides fisheries information to the National Marine Fisheries Service (NMFS) through its Western Pacific Fisheries Information Network (WPACFIN) and to the Western Pacific Regional Fishery Management Council (WPRFMC). The Council is responsible for managing fisheries within the 200-mile Exclusive Economic Zones (EEZ) around American Samoa, Hawaii, Guam, the Commonwealth of the Northern Marianas, and other U.S. possessions in the Pacific.

The historical development of DMWR has been described by Itano (1991). DMWR (initially the Office of Marine Resources) was established in the 1960's to oversee fisheries development projects and conduct resource assessments. In 1972, the development of artisanal fisheries began in earnest as did DMWR's data collection efforts. With assistance from WPACFIN in the 1980's, the data collection program was significantly upgraded and expanded to provide better coverage and statistics for all local boat-based fisheries.

General procedures for DMWR data collectors are to sample the artisanal fisheries two weekdays and one weekend (or holiday) per week, as described in detail by Aitaoto et al. (1991). During sample days, a creel survey is conducted as boats dock at designated harbors between 0500 and 2100 h. The fishermen are interviewed and their catches examined. To produce annual

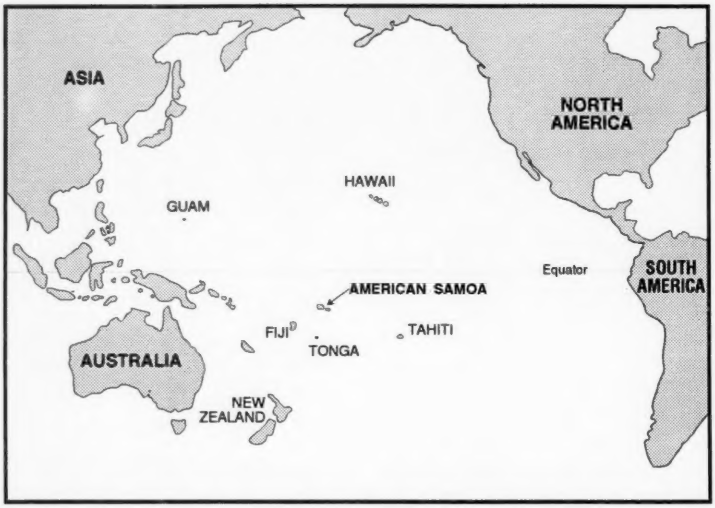

Figure 1.—Location of American Samoa (14° S, 170° W) in the South Pacific Ocean.

catch statistics, the creel survey information is computerized, verified, and expanded to account for times and areas not sampled. In the Manu'a Islands, the fishing fleet is small and the catch from nearly every boat is monitored; data are adjusted for the few trips not sampled. For recreational tournaments, DMWR provides the official weigh-in station and tallies landings from all participating boats.

The shoreline subsistence fishery on Tutuila Island was first examined in the late 1970's by Hill (1978) and Wass (1980). Beginning in 1991, the fishery is again being monitored by a creel and participation survey, conducted 3 days a week, stratified by time of day and type of day (weekday/weekend) (Ponwith, 1992). Catch data were first expanded to the entire study area along the south shore of Tutuila, where 35% of the people live. Then, on a per-capita basis, results were expanded to produce a Territorial catch.

The distant-water fleet that delivers tuna to canneries in American Samoa has been monitored by NMFS, either directly or by contract to DMWR, since 1963. The NMFS port sampling program collects vessel logbooks, length-frequencies of tuna species, and cannery summaries of vessel landings by species and gear type. Sampling procedures are described by Honda et al.[1] and Ito and Yamasaki[2].

Regulations and Enforcement

Few of WPRFMC's regulations have focused on American Samoa's EEZ, because no major commercial fishery operates there at present. A goal, however, will be to insure that local residents have opportunities to participate in future fisheries developments that do occur. Preferential rights for indigenous people are currently being researched, and a control date (1 Jan. 1991) was set for possible implementation of a limited entry program for longline fishing. Occasional poaching by foreign vessels occurs in the EEZ, but no enforcement vessels or aircraft are available for surveillance.

Territorial regulations that apply to the management of local fisheries include record keeping for commercial fishermen, seafood dealers, and fish processors, as well as specific laws (mostly pertaining to reef users) regarding illegal fishing methods, gear restrictions, and species size limits. Enforcement of territorial regulations is at an early stage of development.

[1]Honda, V., G. Yamasaki, and R. Ito. 1988. American Samoa purse seine fishery sampling. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Center., Honolulu Lab., Admin. Rep. H-88-20, 35 p.

[2]Ito, R., and G. Yamasaki. 1988. Status of the American Samoa foreign longline tuna fishery, 1982–86. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., Honolulu Lab., Admin. Rep. H-88-19, 30 p.

Domestic Fisheries

The annual harvest of combined domestic fisheries in 1991 was 587,000 pounds, valued at $993,000 at local market prices. By far the majority of this catch (78%) and value (80%) was taken by the shoreline subsistence fishery (Fig. 2). It should be noted, however, that none of the domestic fisheries is strictly a commercial, subsistence, or recreational enterprise. These terms are used only to describe the principal nature of the fishery because some fish are sold and others are retained for personal use in each fishery. The percentage of fish sold varies consider-

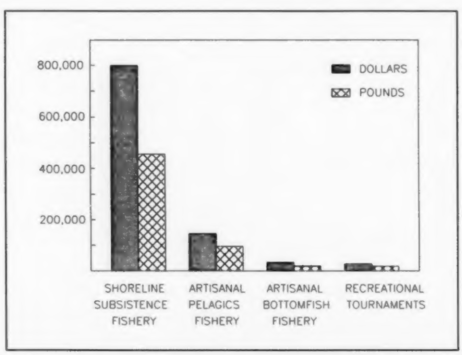

Figure 2.—Annual landings and value of four domestic fisheries in American Samoa in 1991. Units on the vertical axis refer to both dollars and pounds.

ably: Recreational tournaments (10% sold), shoreline subsistence fishery (25%), artisanal bottomfish fishery (65%), artisanal pelagic fishery (85%).

Shoreline Subsistence Fishery

The islands of American Samoa are partially surrounded by a narrow fringing coral reef, the top of which is exposed at low tide. The reeftop and adjacent shallow waters are inhabited by a diverse array of fish and shellfish species (Wass, 1984; USACE[3, 4]) that are harvested by local residents on almost a daily basis throughout the year (Hill, 1978; Wass, 1980; Ponwith, 1992). Most fishing is accomplished by individuals on foot who fish in areas adjacent to their own village. Principal fishing methods used are rod and reel (which accounted for 37% of the annual catch in 1991), handline (25%), free diving (14%), gill netting (9%), gleaning (8%), and throw netting (5%). Gleaning involves the collection of fish and invertebrates at low tide, usually by hand, stick, or steel rod.

The 1991 island-wide subsistence catch on Tutuila Island was 439,000 pounds and was worth $768,000 at the average rate of $1.75/pound (Ponwith, 1992). Expanding these data to include limited catches in the Manu'a islands produces a total subsistence catch in the Territory of 456,000 lb, worth $798,000. The average catch per unit of effort (CPUE) was 3 pounds/gear-h; highest CPUE was obtained by gill netting (12.2 pounds/gear-h), followed by throw net (4.9 pounds/gear-h), free diving (2.9), rod and reel (2.9), gleaning (1.7), handline (1.4), and bamboo pole hook and line (0.7).

Virtually all fish and invertebrate species caught were retained for consumption or sale. Altogether, 69 species or species groups were harvested; fishes accounted for 86% of the total catch by weight. One coastal migratory fish species, the atule or bigeye scad, *Selar crumenophthalmus*, dominated the harvest in 1991 (Table 1). Jacks, surgeonfish, mullet, and octopus made up the majority of the reef-resident species taken. The average sizes of fishes taken were surprisingly small (Table 1), particularly for groupers and snappers which had very low mean weights (0.3–0.4 pound). Some favored species, such as giant clams, *Tridacna* spp., were generally absent in reef catches because of overharvesting.

Table 1.—Catch composition of the shoreline subsistence fishery on Tutuila Island in 1991.

Reef species group		Catch Composition (%)	Average Weight (lb)
Coastal Migrants			
Atule (big-eye scad)	*Selar crumenophthalmus*	46	0.3
Reef Residents			
Jacks	Carangidae	10	1.4
Surgeonfish	Acanthuridae	9	0.5
Mullet	Mugilidae	6	0.9
Octopus	*Octopus* sp.	5	2.2
Groupers	Serranidae	3	0.4
Sea urchins	Echinoid	3	
Palolo worms	*Eunice viridis*	2	
Squirrelfish	Holocentridae	2	
Snappers	*Lutjanus* spp.	1	0.3
Parrotfish	Scaridae	1	
Sea snails	Gastropoda	1	
Other		11	

Total catch: 439,000 pounds

One unique species taken was the palolo worm *Eunice viridis*, a burrowing polychaete. Palolo generally emerge once a year to release their reproductive segments (epitokes) into nearshore waters (Caspers, 1984; Itano and Buckley, 1988). Samoans, who consider the epitokes a delicacy, gather in large numbers (up to 1,000's) at midnight of the predicted night of emergence to collect the epitokes using scoop nets or long lengths of screen. Ponwith (1992) reported that palolo catches were highly variable (3,400 pounds in 1990, 600 pounds in 1991) because of the strength of the swarming event and the presence of offshore winds that concentrate the epitokes near the shoreline, making them more accessible to the villagers.

An opportunity to identify trends in the shoreline fishery was provided by two similar studies conducted in 1979 (Wass, 1980) and 1991 (Ponwith, 1992) on Tutuila Island. During this 12–year period, the island-wide catch decreased by 26%; however, differences in the run strength of the atule, an annually variable migrant to the shoreline area, tend to obscure an even greater decline in catch. In 1979 the atule catch was relatively small, only 13% of the total catch compared to 46% in 1991. By removing this species from the analyses and considering only the reef-resident species, a major drop is apparent in the adjusted island-wide catch (–54%) over the past 12 years, while effort decreased only 8% (Fig. 3).

Downward trends in catch and effort seem even more significant since there was a 46% increase in the human population during the same period (EDPO, 1991). With this influx of people and reduced fishing effort, the per capita subsistence catch on Tutuila Island dropped from 19.4 to 9.8 pounds. Some possible explanations for the reduced catch and effort include a decline in resource abundance (reflected by a drop in CPUE) or sociological changes such as less leisure time, a shift in dietary preferences, or a preference to buy fish at the market rather than to catch them personally. Imports of reef fish from Western Samoa and Tonga have occurred in recent years (at least 10,200 pounds in 1991) and appear to be increasing.

In general, the shoreline subsistence fishery appears to be declining, although it still far exceeds harvests of other domestic fisheries in American Samoa. Two notable exceptions to this apparent decline in interest are the directed fishing efforts for two highly prized species, the atule and palolo.

Artisanal Fisheries

While local fishermen in American Samoa have harvested inshore fishes over the millennia, they have also made significant catches of offshore fishes since the 1970's. Itano (1991) describes in detail several "boom and bust" cycles that occurred over the years as various fisheries development projects were introduced. One of the more lasting projects was the small-boat "Dory Project" (1972–75) in which subsidized dory-type boats were made available to fishermen who then supplied catch information to DMWR. Though the project faded because of a variety of problems, Itano (1991) notes that it

[3]USACE. 1980. Coral reef inventory of American Samoa. U.S. Army Corps Eng., Honolulu, Hawaii, 314 p.

[4]USACE. 1994. Coral reef inventory of American Samoa. U.S. Army Corps Eng., Honolulu, Hawaii.

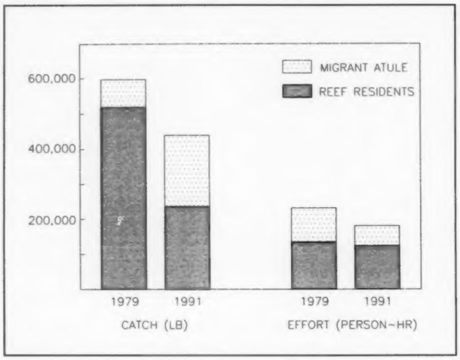

Figure 3.—Comparison of catch and effort in the shoreline subsistence fishery on Tutuila Island in 1979 (Wass, 1980) and 1991 (Ponwith, 1992).

inaugurated the current artisanal fisheries in American Samoa. Although catch statistics from the Dory Project are incomplete, CPUE data are available for comparison to current catch rates.

The two components of the current offshore artisanal fishery are 1) trolling for pelagic fishes in surface waters and 2) vertical handlines (with baited hooks) for bottomfish (Aitaoto et al., 1991). Fishing is typically conducted from small boats (e.g., 28-foot aluminum catamarans) fishing 1–25 miles offshore on 1–day trips. In 1991, boats participating in the pelagic fishery (30 boats) and bottomfish fishery (20 boats) landed relatively small amounts of fish, thus indicating the part-time nature of their participation in the fisheries. The average catch was about 130 pounds per trip in both fisheries, and the annual catch per vessel averaged 910 pounds of bottomfish and 3,030 pounds of pelagic fish.

Artisanal Pelagic Fishery

Most pelagic fishing occurs in coastal waters, near seamounts, where seabird flocks are feeding (thus indicating the presence of baitfish that tuna may also be feeding upon), or at fish aggregation devices (FAD's) deployed around Tutuila Island. FAD's were introduced to American Samoan coastal waters in 1979 and have proven to be a popular way to increase the CPUE of widely dispersed pelagic fishes (Buckley et al., 1989). The lifespan of FAD's ranges about 3–30 months, and in recent years, 1–5 FAD's have been on station at any given time.

The artisanal catch of pelagic fish totaled 94,900 pounds in 1991, worth about $144,200 (this includes the value of pelagic fish retained for personal use) at an average price of $1.52/pound. Catches have ranged from 100,000 to 240,000 pounds in recent years (Fig. 4), and consisted primarily of skipjack and yellowfin tuna (Table 2). CPUE was variable (Fig. 5), as might be expected for oceanic migratory species, but current CPUE's are generally similar to CPUE's obtained during the start-up of the fishery in the 1970's (i.e., the Dory Project).

The recent drop in pelagic landings reflects, in part, recent hurricane-related damage (Hurricanes Tusi in 1987, Ofa in 1990, and Val in 1991), and the departure of several "highliners" from the fishery. Declines in revenue generated by the pelagic fishery (Fig. 6) from 1988 to 1990 were a result of drops in both landings and price; however, revenue made a slight comeback in 1991 owing to an increase in price. The pelagic fishery competes with an inexpensive and readily available supply of frozen fish that is purchased or bartered from foreign longline vessels delivering tuna to the canneries in American Samoa. In some cases, the domestic skippers themselves act as middlemen in such transactions. It is difficult to assess the influence that this fish source has on the market supplied by local fishermen, though Itano (1991) speculates that it inhibits the development of a viable artisanal fishery in the Territory.

Table 2.—Catch composition of the artisanal pelagic fishery, 1989–91.

Pelagic species		Catch in 1989–91 (%) Mean	Range
Skipjack tuna	*Katsuwonus pelamis*	55	48–60
Yellowfin tuna	*Thunnus albacares*	28	26–32
Blue marlin	*Makaira mazara*	6	4–8
Sharks	Miscellaneous	3	2–4
Dolphinfish	*Coryphaena hippurus*	2	2–3
Barracudas	*Sphyraena* spp.	2	1–2
Little tuna	*Euthynnus affinis*	1	0–3
Wahoo	*Acanthocybium solandri*	1	1
Dogtooth tuna	*Gymnosarda unicolor*	1	1–2
Other		1	0.2–1

Mean annual catch (lb): 124,200
Range (lb): 83,500–198,200

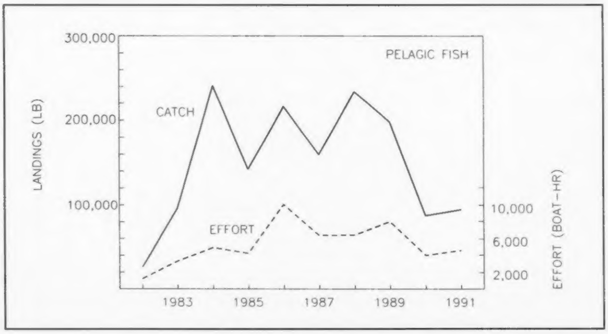

Figure 4.—Annual landings and effort of the artisanal fishery for offshore pelagic fishes.

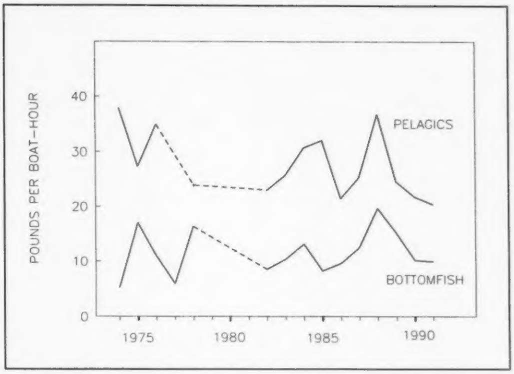

Figure 5.—CPUE trends for artisanal fisheries for bottomfish and troll-caught pelagic fishes. Data in 1977 were insufficient for pelagic catches, and no data were recorded in 1979–81.

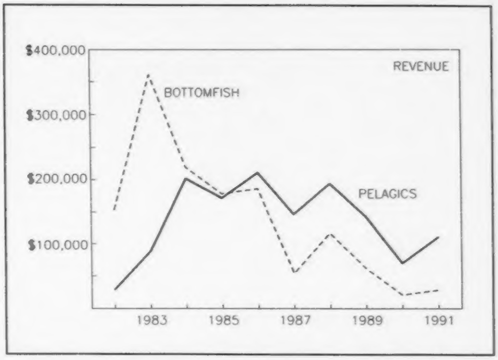

Figure 6.—Annual revenue (inflation adjusted) for artisanal fisheries for bottomfish and pelagic fishes. This graph illustrates commercial sales but does not include the value of fish retained for personal use.

Artisanal Bottomfish Fishery

Bottomfish fishing occurs at depths of 15–100 fm around Tutuila Island and offshore seamounts. Suitable habitat for bottomfish is limited because the islands slope steeply into deep water and there are few seamounts in the Territory. The 100–fm isobath extends 110 n.mi. around the seven islands of American Samoa and 34 n.mi. around its seamounts (Itano, 1991). Dalzell and Preston (1992) estimate that the maximum sustainable yield (MSY) for deep slope bottomfish is about 8–27 t/year.

A small fishery for bottomfish was developed as a result of several government-funded projects in the 1970's and 1980's, and some high-valued fish (e.g., deepwater snappers) were shipped to Hawaiian markets for higher prices. But as these projects terminated and catches dropped, interest waned, and the fishery declined. The fishing grounds were "fished out" and catches probably exceeded MSY during this period (Itano, 1991).

In the past several years, the bottomfish fishery has collapsed to only 14% of its 1985 peak year (Fig. 7), and no fish are being marketed off the island. This decline appears to be due to several factors in addition to overfishing: Decreased subsidies to the fishery (Itano, 1991), the departure of several highliners from the fishery, and hurricane-related damage to local boats.

Snappers, emperors, and groupers accounted for most of the 18,100 pounds of bottomfish landed in 1991 (Table 3). This catch was worth $32,800 (this includes the value of bottomfish retained for personal use) at an average price of $1.81/pound. CPUE has varied between 10 and 20 pounds/boat-h, which is similar to CPUE's from the Dory Project in the 1970's (Fig. 5).

Revenue trends for the bottomfish fishery parallel the decline in catch (Fig. 6). Fishermen are also beginning to experience marketing conflicts with the recent influx of fresh bottomfish imported from Western Samoa and Tonga. In 1991 (the first year for which nearly complete data are available), imports of bottomfish were at least 19,400 pounds, thereby exceeding local landings of bottomfish.

Tournament Fishery

Tournaments for pelagic fishes are popular events in the Territory. Typically, 7–14 local boats and 55–70 fishermen participate in each tournament, which are held 2–5 times per year, each lasting about 3 days. Tournament landings have been monitored almost yearly since 1974.

During 1974–92, the average fishing trip lasted 10 h and caught 12.3 pounds fish, for a daily trip average of 118 pounds (range 0–949 pounds), all species combined. After cancellation

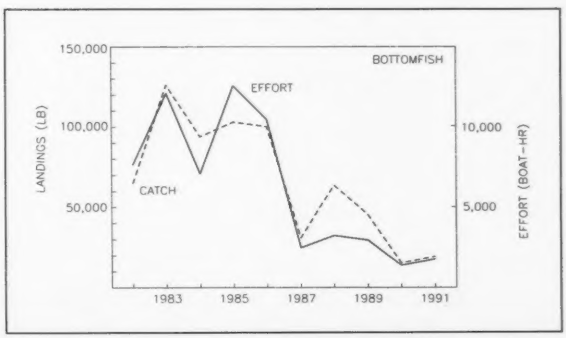

Figure 7.—Annual landings and effort of the artisanal fishery for bottomfish.

of most tournaments in 1990 in the aftermath of Hurricane Ofa, a sharp increase in participation and catches (as well as monitoring efforts) occurred in 1991 (Fig. 8). All reported landings (Fig. 8) are considered minimum estimates because 1) skipjack tuna and sharks were caught but often not reported because there was no tournament prize for them and 2) a fish caught might not be reported if a larger prize-winning one had already been landed.

The species composition of the five tournaments in 1991 consisted primarily of yellowfin tuna, blue marlin, and skipjack tuna (Table 4). Average and maximum weights of fishes caught (Table 4) are smaller than Hawaiian records, perhaps due to a much lower sport fishing effort in American Samoa.

The tournament CPUE for targeted species (blue marlin, yellowfin tuna, wahoo, and mahimahi) has been increasing over the years (Fig. 8), probably for several reasons. The fishermen are using better fishing gear and they have larger boats that can go farther offshore to fish around seamounts. In addition, the introduction of FAD's around Tutuila Island has resulted in higher catch rates (Buckley et al., 1989).

Tournament fishing is becoming increasingly important in American Samoa, and it contributed 3% of the total domestic landings in 1991 in only 16 days of fishing. The catch during this short period nearly equalled the yearly artisanal bottomfish harvest and amounted to 19% of the artisanal pelagic harvest.

Table 3.—Catch composition of the artisanal bottomfish fishery, 1989–91.

Bottomfish species		Catch in 1989–91 (%) Mean	Range
Bluelined snapper	*Lutjanus kasmira*	17	14–20
Redgill emperor	*Lethrinus rubrioperc.*	12	11–14
Gray jobfish	*Aprion virescens*	10	7–14
Longnose emperor	*Lethrinus elongatus*	7	4–10
Lunartail grouper	*Variola louti*	6	5–8
Other groupers	Serranidae	6	2–10
Humpback snapper	*Lutjanus gibbus*	5	4–6
Ambon emperor	*Lethrinus amboinensis*	4	3–5
Squirrel. snapper (ehu)	*Etelis carbunculus*	4	3–6
Jacks (unidentified)	*Carangidae*	4	3–6
Black jack	*Caranx lugubris*	3	3–4
Twinspot/red snapper	*Lutjanus bohar*	3	2–4
Longtail snapper (onaga)	*Etelis coruscans*	3	2–4
Other emperors	*Lethrinidae*	3	2–4
Peacock grouper	*Cephalopholis sonnerati*	2	2–3
Silverjaw jobfish (lehi)	*Aphareus rutilans*	2	1–3
Opakapaka	*Pristipomoides* spp.	2	1–3
Kusakar's snapper	*Paracaesio kusakarii*	2	0–5
Flower snapper (gindai)	*Pristipomoides zonatus*	1	1–2
Other		3	1–5

Mean annual catch (lb): 26,300
Range (lb): 15,400–45,300

Table 4.—Catch composition and weight of fish caught in recreational fishing tournaments. Note that record weights for sharks and skipjack tuna may be artificially low because these were not target species.

Species	Composition in 1991 (%)	Tournament records[1] (lb) Mean	Maximum
Yellowfin tuna	36	16	185
Blue marlin	23	132	542 (636)[3]
Skipjack tuna	19[2]	9	36
Wahoo	8	19	54
Mahimahi	6	23	51
Sailfish	4	75	110
Shark	1[2]	87	125

[1] 1974–1992
[2] Minimum estimate due to incomplete reporting
[3] A nontournament blue marlin weighing 636 pounds was caught in 1984, and a larger one was caught but not recorded (H. Sesepasara, personal commun.).

Commercial Tuna Fishery

In contrast to the small-scale nature of the domestic fisheries, American Samoa is also homeport to a distant-water fleet of large commercial vessels that deliver tuna to the canneries on Tutuila Island. These vessels fish beyond American Samoa's EEZ in the central and western Pacific Ocean. Fleet composition and landings have changed over the nearly 40 years that the canneries have been in operation, but it is beyond the scope of this paper to document these changes (see reports by Otsu and Sumida, 1968; Yoshida, 1975; Doulman, 1987; Schug and Galea'i, 1987; Honda et al.[1]; Ito and Yamasaki[2]).

The current fleet consists of 1) U.S. purse seiners that fish for skipjack and yellowfin tuna (about 30 vessels), 2) U.S. trollers that fish for albacore (about 30 vessels), and 3) foreign longliners that fish for albacore, yellowfin tuna, and bigeye tuna (about 70 vessels, mostly Taiwanese). In addition, transshipments of tuna are delivered to American Samoa by freezer vessels, and foreign sashimi longliners occasionally deliver part of their catch to the canneries.

Annual tuna landings in American Samoa have run about 160,000–220,000 short tons in recent years. Skipjack tuna accounted for most of the deliveries, followed by yellowfin tuna and albacore (Fig. 9). The catch by gear type was purse seine (50%), longline (14%), and troll (1%). The remainder (34%) was fish caught by purse seine and delivered to the canneries by freezer vessels.

Discussion

Domestic fisheries may be small by commercial standards, but they are locally significant to the economy of American Samoa. The yearly harvest, originating primarily from the subsistence fishery on the coral reefs around

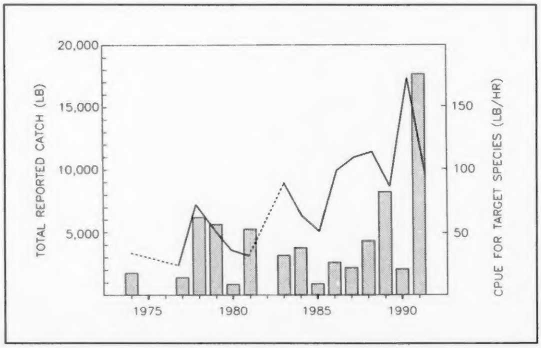

Figure 8.—Total reported catch of all species in fishing tournaments (bars) and CPUE (line) for the four principal target species: Blue marlin, yellowfin tuna, wahoo, and mahimahi. No data are available for 1975–76 and 1982.

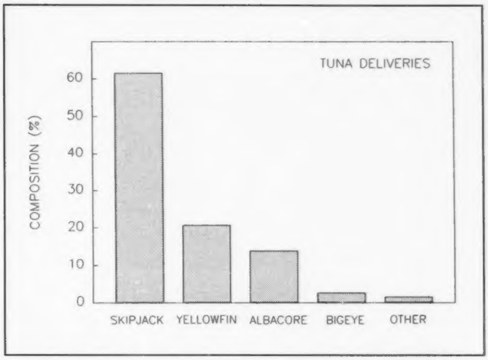

Figure 9.—Species composition of tuna delivered to canneries in American Samoa by the distant-water fleet of large commercial purse seiners and longliners.

the islands, amounted to 587,000 pounds worth nearly a million dollars in 1991. This dollar value does not fully represent the economic or social significance of this resource because of the subsistence component of Samoan culture and the generally low wage scale received by islanders who are employed.

A general decline in the catch and effort in the shoreline subsistence fishery has been noted, as might be expected in a society undergoing a shift from a subsistence economy to a cash economy. Nonetheless, the shoreline subsistence fishery still accounts for the major share of the total domestic catch and value. Consequently, there is a continuing need for the islands to better protect their reef resources from adverse impacts, some of which are readily apparent (e.g., pollution, siltation, destructive fishing practices). The scarcity of some highly sought reef species (e.g., giant clams), and the small sizes of fishes presently caught in the shoreline fishery also indicate that overfishing is probably occurring for some species.

Which of the domestic fisheries, if any, holds promise for further development? For the reasons outlined above, the shoreline subsistence fishery is an unlikely candidate. Similarly, the bottomfish fishery has already peaked because of the limited amount of suitable bottom habitat required by those species. However, considering the low level of fishing that occurs at present, the bottomfish fishery could withstand some increase in harvest.

Probably the least developed domestic fishery is that for pelagic fishes (tuna, marlin, swordfish, etc.) in the offshore waters of the Territory. These fishes are presumably part of large oceanic stocks which are unlikely to be diminished by small-scale artisanal fishing efforts. Rather, any expansion of this fishery will likely depend on several other factors. First, there are few local vessels at present that are large enough to undertake the multiple-day fishing trips necessary to fish profitably. None have freezer capabilities, and an adequate shoreside supply of ice is not yet available. Second, an increased supply of fish would quickly saturate local demands for fish, thus necessitating off-island marketing and shipping costs. Third, although pelagic resources are vast, their local availability may fluctuate because of seasonal variations or local depletions. Thus, a successful fishing enterprise by local residents would need to resolve important issues regarding vessel capabilities, marketing, and the availability of high-valued pelagic fishes in Territorial waters. However, an expansion of the sport fishery for pelagic fishes is not similarly encumbered, and indeed appears to be gaining popularity.

Acknowledgments

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Guam's Small-Boat-based Fisheries

ROBERT F. MYERS

Introduction

Nearly 900 finfish species and a similar number of macroinvertebrate species inhabit the waters surrounding Guam. Approximately one-third of the species of finfishes and a smaller contingent of the invertebrates are utilized in the subsistence or commercial fisheries. Guam's exploited fisheries resources can be divided into the following five major groups based on biology and harvest method: Marine invertebrates, reef fishes, bottomfishes, pelagic fishes, and bigeye scad. Marine invertebrates include crustaceans, shelled mollusks, cephalopods, and echinoderms (Amesbury et al., 1986).

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ABSTRACT—Recent trends in Guam's small-boat fisheries and current knowledge of their biology, management, and economics are summarized. Annual estimates of participation, effort, and harvest are given for the pelagic and bottomfish fisheries for 1980–91 and for the spearfishing and atulai fisheries for 1985. The pelagic fishery is the largest, with annual landings ranging from 168 to 364 metric tons (t), followed by the bottomfish fishery (14–43 t), spearfishing fishery (5–17 t), and bigeye scad fishery (3–20 t). All of the pelagic species are highly migratory and require regional management. They are heavily exploited by Guam-based domestic purse-seine and foreign longline fisheries, but region-wide catch and effort as well as the status of the stocks are largely unknown. Bottomfish and reef-fish stocks are shared to an unknown extent with those of the northern Marianas and are locally manageable. Certain vulnerable species of bottomfishes and reef fishes are overfished. Bottomfish and speared fish landings are dominated by small species with high turnover rates.

Echinoderms are generally harvested by reef gleaners and rarely with the aid of boats. Other invertebrates are harvested by hand or spear and with or without the use of boats. Reef fishes include all finfishes associated with coral reefs and adjacent sand flats and seagrass beds, as well as a small number of primarily estuarine species and are taken primarily by nets, spear, and hook and line with or without the use of boats.

Bottomfishes include reef fishes that occur beyond the seaward margin of the reef as well as deep-dwelling coastal fishes occuring to depths of approximately about 300 m that are taken by hook and line from boats. Pelagic fishes include migratory open-ocean species as well as a few coastal pelagic and reef species taken by lines trolled from a moving boat, longline, or ikashibi. The latter two methods have been rarely employed and are not currently in use. Nearly all pelagic landings consist of the following five species: Mahimahi, *Coryphaena hippurus*; wahoo, *Acanthocybium solandri*; skipjack tuna, *Katsuwonus pelamis*; yellowfin tuna, *Thunnus albacares*; and blue marlin, *Makaira mazara*. The bigeye scad, *Selar crumenophthalmus*, locally known as atulai, is a coastal pelagic species that undergoes seasonal migrations and is taken by a variety of methods from shore as well as from boats. Boats are used in coordination with a large number of shore-based snorkelers or scuba divers to set large nets around shallow inshore aggregations. The only offshore boat-based method used for this species is jigging at night with the aid of lights.

The original Chamoru inhabitants were expert fishermen and seafarers. Accounts by the early Spanish visitors indicate that they fished on the high seas for such formidable species as marlin and used numerous methods to catch reef and bottomfish from boats as well as from the shoreline (Amesbury et al., 1986). Throughout the Spanish period, the Chamorus were persecuted and an attempt was made to confine them to the island of Guam. Most of the male population was killed, and subsequent generations were of mixed blood. By the 1860's, there were only 24 outrigger canoes on Guam, all of which were used only for fishing inside the reef.

By the begining of the American period in 1898, the indigenous inhabitants had lost many of their seafaring and fishing skills as well as the native names of many of the offshore species. Small outboard and inboard powered boats did not become commonplace until after World War II. Fishing remained the primary motivation for boating, and the methods in use today were well established by the mid-1960's. Unlike many U.S. areas, the concept of fishing for sport is relatively new, and the use of "recreational-type" boating and fishing equipment and techniques for subsistence and commercial purposes is well established.

Trolling is the most popular and important fishing method and was employed on 85% of the boat trips during fiscal year 1991. Bottomfishing with hook and line using poles, handlines, or electric reels from either an anchored or a drifting boat was the second most important method. Spearfishing and jigging under a nightlight for bigeye scad followed in importance. Other rarely used methods include spincasting, longline, and ikashibi.

Procedures

As presently designed, the offshore fisheries survey is a combined fixed-point and roving survey. For the fixed-point portion, personnel from Guam's Division of Aquatic and Wildlife Resources (DAWR) are stationed at one or more major boat landings during a given time-frame for a given number of days each month. All returning fishing parties are interviewed and, when possible, their catch is examined and samples measured or weighed. A log of all departing and returning fishing parties is also kept. The roving survey consists of a twice-a-day circuit in which all empty trailers attached to vehicles and the time of day are noted at each location. Information derived from the site log and the roving survey are used to calculate proportionality values based on the proportion of island-wide fishing activity occurring at the sampled site and the proportion of 24-hour fishing activity actually sampled at the sampled site. The proportionality values used to expand for site totals are method-specific, but those used to expand for island-wide totals are not, since the roving survey does not have the capability of obtaining information on methods. A set of standardized mathematical formulas is used by the Guam Offshore Expansion System (GOES), and its algorithms are used to expand sample-day totals into estimates of monthly, quarterly, and annual totals and their standard errors (SE) and confidence limits (CL). The GOES was prepared by CIC Research, Inc.[1], San Diego, Calif.) for the National Marine Fisheries Service (NMFS) and is available from the NMFS Honolulu Laboratory as Administrative Report H-83-21C. The inherent flexibility of GOES allows changes in sample periods, sites, and methods of determining proportionality constants in response to manpower or budgetary constraints as well as changes in the fisheries. The accuracy of the expansions is limited by the accuracy of the assumption that the sampled time-frames and sites are representative of the entire 24-hour period for the island as a whole. The precision of the expanded estimates is dependent on the sample size.

Prior to the implementation of the GOES, less reliable methods were used to estimate fishing activity from nonsampled sites. The original expansions assumed that activity from the sampled launch site, the Agana Boat Basin, was 50% of the island wide total. This was based on limited counts of boats using other launch sites during 1977–78. The expansions for 1977–82 were subsequently revised by using a set of proportionality figures based on observations made after implementation of the GOES. Surveys were initially limited to the hours of 0600 to 2100 or some portion within that time period. Fishing methods that occured at night were frequently undersampled. Therefore, in 1985 the survey period was divided into two shifts with the late shift extending as late as 2400 hours, and in 1986 it was further extended with the morning shift as early as 0500 hours. With implementation of a boating activity log, it became easier to track boats that could not be intercepted, allowing greater flexibility in the survey shift hours without compromising the comparability of results between years. Specific changes in methods, hours, or sites are detailed in annual reports produced by the DAWR.

The annual estimates of participation, effort, catch, and economics presented here were compiled from a combination of sources. The DAWR and NMFS each generate GOES output from the same data base on different, incompatible computer systems and have different reporting requirements. DAWR expands by gear and fiscal year (FY). NMFS expands by calendar year and by fishery, based on the species caught being categorized as either pelagic or bottomfish, and includes all methods for each of these respective species groups. Personnel, time, and hardware constraints made it impossible to generate standardized output for all parameters and methods. Annual estimates based on the sum of monthly expansions differ slightly from those based on a single period expansion. Annual CL and SE are known only for period expansions and are not presented herein. Whenever possible, information is presented in metric units by calendar year and method based on a period expansion. For some years and methods annual estimates are based on the sum of monthly expansions. All economic information is from annual summaries of commercial receipts compiled by NMFS. All annual estimates for trolling and bottomfishing are based on 362–day expansions (363 days in leap years) with landings from the annual 3-day Guam International Fishing Derby (GIFD) added in. Fishing by nonderby participants during the 3-day event is considered negligible. Annual estimates for spearfishing and night-lighting for atulai exclude the GIFD and are based on full monthly or annual expansions.

Summary data for the pelagic fishery are based entirely on NMFS output. In 1982 and 1985, only 1.7% and 0.2% of pelagic landings were by longline or ikashibi. An even smaller portion of the annual landings consists of sharks caught by other methods. Therefore, the pelagic fishery is considered synonymous with trolling since 98% or more of all annual landings are taken by this method.

Summaries of participation, effort, and catch data for the bottomfish fishery are based on DAWR expansions only and include all species caught by that method. Species composition is based on FY80–91 expansions. Economic summaries are based on NMFS data which exclude sharks and a small number of nonbottomfish species, but include bottomfish species caught by other methods. These differences are not considered large enough to affect the conclusions. Species composition for all other methods are based on fiscal year period expansions from October 1985 through September 1991.

The Fisheries

Pelagic Fishery

Guam's pelagic fishing fleet consists primarily of small recreational trolling boats that are either towed to

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

launch sites or berthed in marinas. Presently most of vessels are <10 m long and are typically owner-operated by persons who earn a living outside of fishing. However, almost everyone sells a portion of their catch at one time or another, and it is impossible to make a distinction between recreational, subsistence, or commercial fishermen. A small but rapidly growing segment of the fleet are marina-berthed charter vessels that tend to be larger than the owner-operated vessels, ranging in length from 8 to >15 m. A small number of similar boats are operator or corporation-owned and are used for a variety of other recreational purposes as well as fishing.

The Catch

Estimated overall pelagic landings have varied widely from year to year, ranging from a low of 168 metric tons (t) in 1987 to 364 t in 1991 (Fig. 1). A long-term trend is not detectable, but there does seem to be a slight general increase since 1987. Annual catches consist nearly entirely of five major species: Mahimahi, wahoo, skipjack tuna, yellowfin tuna, and Pacific blue marlin. Minor components include rainbow runner, *Elagatis bipinnulatus*; great barracuda, *Sphyraena barracuda*; kawakawa, *Euthynnus affinis*; dogtooth tuna, *Gymnosarda unicolor*; sailfish, *Istiophorus platypterus*; and shortbill spearfish, *Tetrapturus angustirostris*. Approximately a dozen additional species are landed incidentally each year.

Mahimahi landings exceeded those of all other species during 7 of the last 12 years, making it the single most important species of the pelagic fishery (Fig. 1). Annual landings ranged from 13 to 182 t, with no detectable trend or cycle. Mahimahi are seasonal, occurring during the winter and spring with a peak in March, although a few may be found throughout the year. More than any other species, the success of the mahimahi run determines whether it is a good or bad fishing year. No attempt has been made to compare catches from different western Pacific locations in a systematic manner. It remains unknown whether a good Guam run is the result of a healthy western Pacific year class or is due to vagaries of oceanographic conditions that concentrate the run near Guam.

Annual landings of wahoo ranged from 15 to 72 t. There is considerable variability from one year to the next with no apparent trends, and in only one year, 1985, did wahoo landings exceed those of all other species. Wahoo are caught throughout the year, but November is typically the best month. At that time, small wahoo of 2–4 kg are common. Most wahoo are immature, but mature fish in the 14–22 kg range are occasionally caught throughout the year. Wahoo are often caught relatively close to shore, and catches may increase during periods of high effort for mahimahi which may be in closer to shore during times of great abundance.

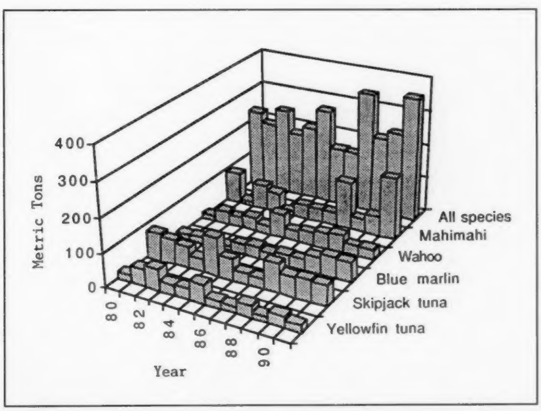

Figure 1.—Estimated annual landings of all pelagic fishes, mahimahi, wahoo, blue marlin, skipjack tuna, and yellowfin tuna by the Guam small-boat pelagic fishery during 1980–91.

Skipjack tuna is the second most important species with annual landings exceeding those of all others during 4 of the last 12 years. Landings are highly variable, ranging from 27 to 113 t (Fig. 1). Skipjack tuna occur in surface feeding schools throughout the year and are often the most easily caught fish, particularly when other species are scarce. However, the relatively low marketability of skipjack tuna makes them less desirable, so many boats do not target them and catches are probably poor indicators of relative abundance. The skipjack tuna caught by trolling near Guam are typically in the 2–6 kg range, but occasional fish weigh up to 9 kg. Skipjack tuna are heavily exploited by a large fleet of domestic purse seiners operating out of Guam. The effects of this exploitation on the stocks and the state of the stocks are unknown.

Annual yellowfin tuna landings were consistently lower than those of skipjack tuna, ranging from 16 to 62 t. Yellowfin tuna are highly valued, and relatively low catches are a reflection of low availability to surface trollers. Yellowfin tuna reach a large size (>160 kg), but most caught by local trollers are in the 2–20 kg range. Occasionally larger fish up to 70 kg are caught. Yellowfin tuna form the basis of the Guam-based foreign longline fishery and are of great importance to the domestic purse seine fishery. The effects of these fisheries on the availability of fish to the troll fishery as well as on the stocks themselves are unknown. Even if the yellowfin tuna stock is not overfished, interception of Guam-bound fish by the more efficient longliners and purse seiners could reduce their availability to the local trollers.

Annual blue marlin landings have increased significantly over the last 12 years, ranging from 15 t in 1980 to 62 t in 1990 (Fig. 1; $r^2 = 0.831$, $P<0.001$). In 1990, blue marlin landings exceeded those of all other species. The most rapid growth in landings occurred from 1988 to 1990. This is attributable to

rapid growth of the charter fleet which tends to target blue marlin more often than the noncharter segment of the fleet. Blue marlin are seasonal; the best catches occur during the warmest months from June to September. Most of the troll-caught fish are small, <70 kg, and are males. Occasional blue marlin are caught throughout the year, including large females of 140–400 kg.

Participation and Effort

The exact number of boats or people participating in the troll fishery are unknown. The GOES enumerates boat-trips and person-trips. Therefore, a "threshold" C/E model is used by NMFS to estimate the annual number of boats participating in the fishery. The estimated number of boats increased more than twofold, from 115 to 282 between 1980 and 1989. The number has dropped somewhat since then, but more recent figures are considered low since the survey does not include boats that fish exclusively from unsampled sites which include a new marina that opened in early 1991. The increase in the number of boats over the 12–year period is significant (r^2 = 0.637, P<0.01)

The estimated annual number of boat trips ranged from 6,287 in 1981 to 12,523 in 1991; most of the increase ocurred after 1987 (Fig. 2). The number of boat hours spent trolling also increased significantly during the past 12 years (r^2 = 0.555, P<0.01), reaching a peak of nearly 59,000 in 1988. However, the number of hours per trip has decreased in recent years because of the increasing proportion of charter trips (r^2 = 0.775, P<0.001). Charter vessels typically carry more people but engage in shorter fishing trips than noncharter vessels.

Catch Rates

Catch rates as catch per unit of effort (CPUE) are calculated by dividing the total annual landings of each species by the total number of boat-hours spent fishing (gear in use). Since it is impossible to allocate species-specific effort, catch rates for a given species calculated in this manner may be influenced by effort targeted towards other species. Catch rates for mahimahi and wahoo fluctuated widely over the past 12 years with no apparent trend (Fig. 3). Catch rates for skipjack tuna show a general decline with the exception of a sharp peak in 1984, and catch rates for yellowfin tuna declined significantly during the past 12 years (r^2 = 0.408, P<0.05). Catch rates for blue marlin increased significantly over the past 12 years (r^2 = 0.722, P<0.001). This is probably a result of the changing composition of the fleet toward more boats that are larger and better equipped to target and catch blue marlin. Recent low catch rates for skipjack tuna are likely due to economic reasons since that species is relatively unmarketable and many boats do not target it. The decline in catch rates for yellowfin tuna cannot be attributed to economic reasons since that species is highly valued and often targeted. When other factors are considered such as declining average and winning sizes at an annual fishing derby, it seems plausible that the reasons for the decline are related to the species' availability. Lower availability of yellowfin tuna, particulary the larger size classes, could be a result of either changes in the stock or of interception by competing fisheries.

Economics

Guam's small-boat trolling fishery consists of recreational, subsistence,

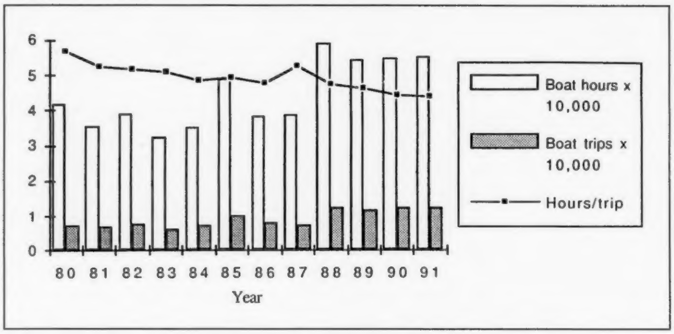

Figure 2.—Estimated annual number of boat trips, boat hours spent trolling, and hours spent trolling per boat trip around Guam during 1980–91.

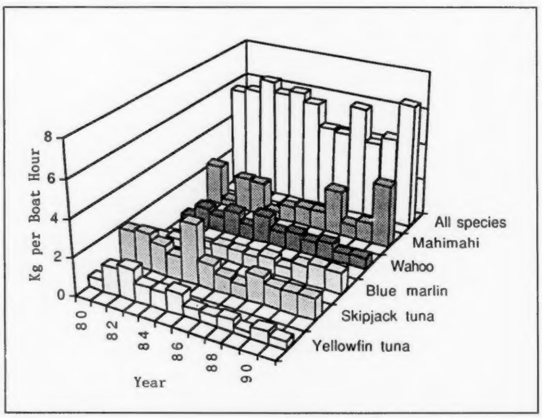

Figure 3.—Catch rates as kg per boat hour spent fishing for all pelagic fishes, mahimahi, wahoo, blue marlin, skipjack tuna, and yellowfin tuna by the Guam small-boat pelagic fishery during 1980–91.

and commercial fishermen, many of whom also engage in other methods of fishing. Most charter boat captains and crew are not employed elsewhere, but most other fishermen hold nonfishing jobs. Charter boat captains and crew generally supplement their pay with tips and proceeds from the sale of the day's catch. Many noncharter fishermen occasionally sell part of their catch, while a minority regularly sell all or most of their catch.

Over the past 12 years, an estimated 42% of the pelagic fish harvest was sold, generating inflation-adjusted annual revenues ranging from $340,532 to $635,006 (Fig. 4). The economics of Guam's trolling fishery is complex and has undergone numerous changes during the past 12 years. Inflation-adjusted revenue per trip has declined by 54% since 1983 (Fig. 5; $r^2 = 0.868$, $P<0.001$). This is due to a number of factors including loss of markets, when there is inadequate availability, inability to efficiently process and freeze or export fish when there is a glut, and competition from other sources that either import inexpensive frozen fish or dump inexpensive rejected longline-caught fish on the local market. The Fisherman's Cooperative has never had widespread support among fishermen, and even members often do not support it by selling their fish elsewhere if offered a higher price. Continued disunity among the troll fishermen hinders them from gaining much political or public support. The charter segment of the fishery remains healthy since only a small portion of revenues are derived from the sale of catches.

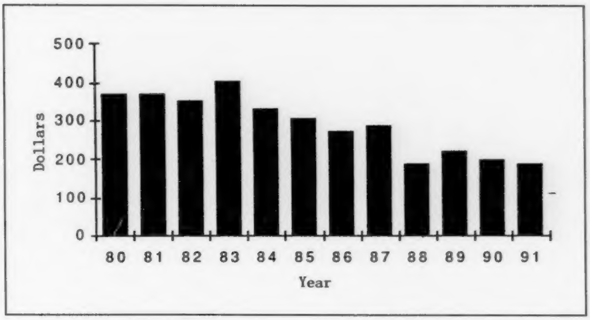

Figure 5.—Inflation adjusted revenue per trolling trip during 1980–91.

Bottomfish Fishery

Bottomfishing is defined here as fishing from an anchored or drifting boat with hook and line without the aid of floodlights. Guam's bottomfish fishery is a small-scale commercial, subsistence, and recreational fishery that operates primarily from boats <25 feet in length. Nearly all fishing is done by Guam residents from owner-operated vessels, but occasionally tourists and residents fish from relatively large charter boats. Historically, the fishery has experienced considerable fluctuations in annual harvest primarily because of the high turnover rates of a few full-time highliners.

The fishery may be divided into two components based on depth and species. The shallow-water component (<150 m) is the larger of the two and usually targets the red-gilled emperor, *Lethrinus rubrioperculatus*, as well as an assemblage of other emperors, snappers, and groupers. The deep-water component (150–250 m) targets the snapper, *Pristipomoides* spp., complex. A few species (most notably jobfish, *Aprion virescens*, and black jack, *Caranx lugubris*), equally abundant in both the shallow and deep zones, are grouped in the shallow fishery and excluded from the deep fishery for purposes of this paper. The larger size of the shallow-water component is the result of greater participation because of the lower expenditure and relative ease of fishing closer to shore. Small spincasting reels are often used for the shallowest bottomfishing, and electric reels, which may have multiple hooks per line, are used for deeper bottomfishing. Handlines are rarely used. Nearly all participants in the bottomfish fishery also troll for pelagic species, and most participate in both methods on the same trip. All the shallow bottomfish species are coral reef fishes, and they are subject to harvest by both offshore and inshore reef fishery methods. However, only small quantities of the most important bottomfishery species are harvested by these methods, and the most important reef fishery species form a negligible component of the bottomfish fishery.

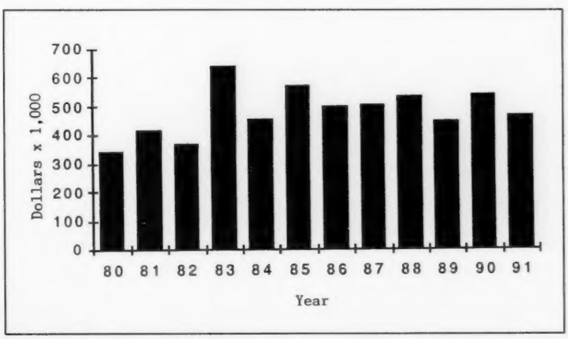

Figure 4.—Inflation adjusted annual revenues for troll-caught pelagic fishes during 1980–91.

The Catch

Since 1980 the annual estimated bottomfish catch has fluctuated between 14 and 43 t (Fig. 6). The fluctuations are due primarily to changes in the fishery rather than to changes in the stocks. However, decreasing catches

of some of the larger deepwater species are probably stock related. Catches for the past year may be slightly underestimated because of the opening of the Agat Marina which is not yet surveyed. It is believed that a larger proportion of the participation for bottomfish fishing occurs there than at the primary sampling location, the Agana Boat Basin.

Snappers and emperors are the most important bottomfish families, represent an estimated 38.5% and 29.5% of the weight of the harvest from FY1980–91 (Table 1), respectively. Only three other families represented more than 2% of the catch: Groupers (10.0%), jacks (9.4%), and requiem sharks (5.4%). Squirrelfishes, goatfishes, wrasses, dogtooth tuna, and triggerfishes each represented between 1 and 2% of the catch. At least 35 other families collectively represented the remaining 2.6% of the catch. Although sharks collectively represented 5.6% of the catch, they are not targeted and are often killed and discarded at sea. The landed catch is an unreliable indicator of stock size. An estimated 67.7% of the 1980–91 harvest consisted of shallow-water species, and 32.3% consisted of deep-water species.

The red-gilled emperor is the most important bottomfish species and represented 24.2% of the FY1980–91 estimated harvest, 82.1% of the emperor harvest, and 35.8% of the shallow-water harvest. Other important shallow-water species with percentage of total bottomfish catch indicated, were the jobfish (5.6%); the groupers (*Epinephelus fasciatus*, 3.4%; *Variola louti*, 2.8%; and *Cephalopholis sonerati*, 1.2%); the jacks (*Caranx lugubris*, 3.2%; *Carangoides orthogrammus*, 1.3%; *Caranx melampygus*, 1.2%; and *C. ignobilis*, 1.2%); and the snappers (*Lutjanus bohar*, 1.5%; and *L. kasmira*, 1.5%). The mean sizes of 5 shallow species (*Lethrinus rubrioperculatus*, *Cephalopholis urodeta*, *Epinephelus fasciatus*, *Variola louti*, and *Aprion virescens*) have remained essentially unchanged since 1980 (Davis[2]). The red-gilled emperor, above-listed groupers, and most others in the fishery are small species with high turnover rates. This is indicative of a mature fishery in which the larger species are overfished.

Among the deepwater species, 87.5% consisted of snappers of the *Pristipomoides* complex. The most important species with percentage of total bottomfish catch indicated, were yellowtail kalikali, *Pristipomoides auricilla*, 6.2%; ehu, *Etelis carbunculus*, 3.9%; lehi, *Aphareus rutilans*,

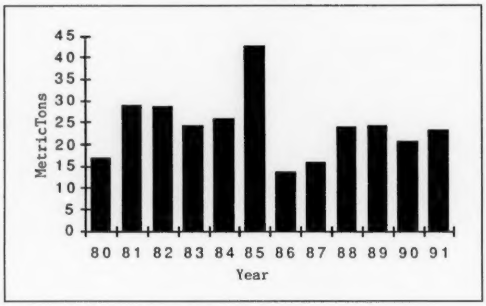

Figure 6.—Estimated annual bottomfish landings during 1980–91.

Table 1.—Species composition of Guam bottomfish landings during FY 1980–91.

		Percent of		
	Total landings (kg)	Total landings	Shallow portion	Deep portion
Sharks	14,996.5	5.4	8.0	
Holocentridae (Squirrelfishes)	4,259.4	1.5	2.3	
Serranidae (Groupers)	27,513.3	10.0	10.6	8.7
Cephalopholis sonerati (Tomato grouper)	3,384.5	1.2	1.8	
Epinephelus fasciatus (Black-tipped grouper)	9,239.4	3.4	5.0	
E. octofasciatus (Eightbar grouper)	7,696.7	2.8		8.7
Variola spp. (Lyretail groupers)[1]	7,567.9	2.8	4.1	
Carangidae (Trevallys)	25,824.7	9.4	12.2	3.5
Caranx ignobilis (Giant trevally)	3,435.5	1.2	1.8	
C. lugubris (Black trevally)	8,721.4	3.2	4.7	
C. melampygus (Bluefin trevally)	3,316.2	1.2	1.8	
Carangoides orthogrammus (Yellow-spotted trevally)	3,685.7	1.3	2.0	
Seriola dumerili (Amberjack)	3,067.7	1.1		3.5
Lutjanidae (Snappers)	105,844.2	38.5		
Shallow snappers	26,630.1	9.7	14.3	
Aprion virescens (Jobfish)	15,294.1	5.6	8.2	
Lutjanus bohar (Red snapper)	4,174.5	1.5	2.2	
L. kasmira (Bluelined snapper)	4,099.2	1.5	2.2	
Deep snappers	77,716.9	28.2		87.5
Aphareus rutilans (Lehi)	10,824.7	3.9		12.2
Etelis carbunculus (Ehu)	10,843.1	3.9		12.2
E. coruscans (Onaga)	10,511.8	3.8		11.8
Pristipomoides auricilla (Yellowtail kalekale)	17,065.5	6.2		19.2
P. filamentosus (Pink opakapaka)	6,153.9	2.2		6.9
P. flavipinnis (Yelloweye opakapaka)	10,043.7	3.6		11.3
P. zonatus (Gindae)	9,712.1	3.5		10.9
Lethrinidae (Emperors)	81,234.6	29.5	43.6	
Lethrinus rubrioperculatus (Redgill emperor)	66,722.0	24.2	35.8	
Mullidae (Goatfishes)	3,880.3	1.4	2.1	
Sphyraenidae (Barracudas)	909.3	0.3	0.5	
Labridae (Wrasses)	2,981.5	1.1	1.6	
Acanthuridae (Unicornfishes)	1,866.9	0.7	1.0	
Scombridae (Tunas)	3,208.7	1.2	1.7	
Balistidae (Triggerfishes)	3,433.5	1.3	1.8	
Total nonsnapper deep species	11,086.0	4.0		12.5
Total deep species	88,785.3	32.3		100.0[2]
Total shallow species	186,401.9	67.7	99.8[2]	
Total all bottomfish species	275,187.2	100.0		

[1] Primarily *V. louti* but also includes a small proportion of V. *albimarginata*.
[2] Excludes incidental taxa not tabulated.

[2]Davis, G.W. 1992. Territory of Guam 1991 bottomfish fisheries performance. *In* Bottomfish and seamount groundfish fisheries of the western Pacific region. 1991 Annu. Rep. West. Pac. Reg. Fish. Manage. Counc., Honolulu, Hawaii.

3.9%; onaga, *E. coruscans*, 3.8%; yelloweye opakapaka, *P. flavipinnis*, 3.6%; gindai, *P. zonatus*, 3.5%; and opakapaka, *P. filamentosus*, 2.2%. The most important nonsnapper deepwater species were the large eightbar grouper, *Epinephelus octofasciatus*, 2.8%, and the amberjack, *Seriola dumerili*, 1.1%. Grouper was rarely caught and did not even appear in the sampled catch during most years. Also, catches of onaga, another large and the most highly prized of the deepwater snappers, decreased considerably during the past 6 years. Sample sizes for both of these species were inadequate for year-to-year comparisons, and in some years they were not even encountered in the survey. However, the mean sizes of five important species (*Pristipomoides auricilla, P. flavipinnis, P. zonatus, Etelis carbunculus*, and *Aphareus rutilans*) have remained essentially unchanged since 1980 (Davis[2]).

Participation and Effort

The estimated number of vessels in the bottomfish fishery has increased significantly over the past 12 years from 24 to 173 boats in 1991 (r^2 = 0.702, $P<0.001$). The current number could be higher since the Agat Marina, which opened in early 1991, is not sampled. However, long-term trends in overall effort as boat trips and boat hours are not apparent (Fig. 7). This apparent contradiction is due to the effects of a few commercial highliners that dropped out of the fishery in 1986. There has been a short-term trend toward increasing effort since then, and this is expected to continue.

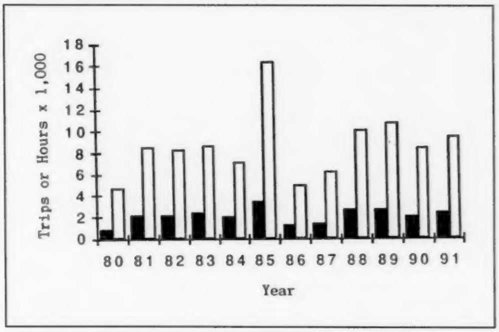

Figure 7.—Estimated annual number of boat trips and boat hours for the bottomfish fishery during 1980–91.

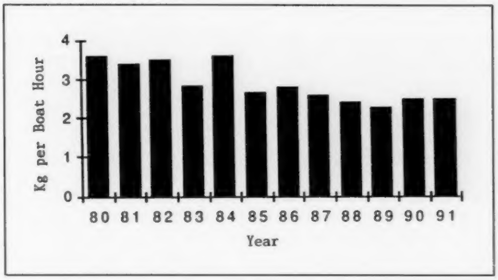

Figure 8.—Catch rates (kg/boat-hour) for the bottomfish fishery during 1980–91

Catch Rates

The annual catch rate for the bottomfish fishery has decreased significantly over the past 12 years (Fig. 8; r^2 = 0.718, $P<0.001$). This may be a result of a few commercial highliners dropping out of the fishery after 1985. With the exception of 1983, catch rates were significantly higher (3.4–3.6 kg/boat-hour) for 1980–85 than all years since then (2.3–2.8 kg/boat-hour). However, the catch rate has remained steady since 1986, indicating that the fishery is stable.

Economics

Nearly all of Guam's bottomfish fishermen hold jobs outside the fishery, and only a small minority sell their catch. However, high turnover rates among a few full-time highliners have greatly influenced annual catch and effort estimates, particularly prior to 1986. Over the past 12 years, an estimated 31% of the bottomfish catch entered the commercial market with annual inflation-adjusted revenues ranging from $22,994 to $114,176 (Davis[2]; Fig. 9). After a 1983 peak, revenue per trip declined sharply and has remained between $103 and $159. Inflation-adjusted average price of bottomfish has remained between $5.64 and $7.67 /kg during the past 12 years. The trend has been a slow and steady decline offset by a sharp rise between 1988 and 1989. Although the supply for fresh local bottomfish has never met the demand, competition from inexpensive imports from the neighboring islands has kept the price depressed and is expected to continue to do so.

Reef-fish Fishery

Guam's reef-fish fishery is composed of several fisheries based on method and logistics. The bulk of the fishery is shore-based (Hensley and Sherwood, 1993) and not considered here. The boat-based portion consists primarily of spearfishing and, to a minor extent, of other methods also used in the shore-based fishery. The minor methods include the use of various nets, spin-casting, and gleaning. Since these methods are infrequently encountered, not expanded separately, and collectively represent less than 1% of the annual estimated boat-based harvest, they are not considered here.

Nearly all spearfishing activity with boats occurs from owner-operated

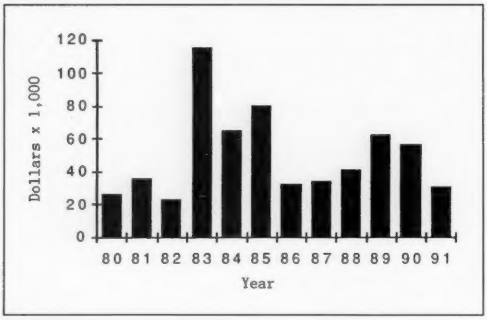

Figure 9.—Inflation adjusted annual revenues for the bottomfish fishery during 1980–91.

rather than chartered boats. The fishery is highly seasonal and the highest mean monthly participation, effort, and landings occur in June, the lowest in March. This seasonality is due to weather and sea conditions which render northwestern clockwise through southeastern exposures inaccessible because of high seas and surf. The fishery consists of two components based on whether or not scuba equipment is used. The range of species targeted is quite broad and includes nearly all coral reef-dwelling finfishes ≥12 cm, crustaceans, and mollusks, the latter picked up by hand incidentally. There is considerable overlap among species targeted by the shore-based spearfishing fishery and shallow bottomfish fishery. Estimates of participation, effort, and catch are crude since it is difficult to get statistically useful sample sizes. Spearfishing is an infrequently encountered method that often occurs outside the surveyed time-frame, and tends to occur more frequently from under- or unsampled launch sites. Considerable spearfishing activity occurs at night and parties return between 2100 and 2400 hours. Since this component of the fishery was not monitored until FY 1985, only information beginning with that year is considered here. Estimates of catch and effort are given for calendar years, but species composition is available only for fiscal years.

The Catch

Annual catch estimates since 1985 have varied widely from 5 to 17 t with a trend toward increased landings (Fig. 10). Prior to 1989 the bulk of the catch was caught by snorkelers, but for the past 3 years 50% or more of the landings have been caught by scuba divers. A broad range of species is targeted including nearly all coral reef dwelling finfishes ≥12 cm as well as incidental crustaceans and mollusks. Over 100 species have been observed in a given survey year, and probably another 50 species are landed but not encountered by the survey.

Since FY1985, 36% of the catch has consisted of parrotfishes (Scaridae), followed by surgeonfishes (Acanthuridae, 19%), and wrasses (Labridae, 7%) (Table 2). Other important finfish families include the groupers (6%), rudderfishes (5%), snappers (3%), jacks (3%), and squirrelfishes (2%). The most important invertebrates are spiny lobsters (4%), primarily *Panulirus penicillatus* which are speared, and topshell (2%) which are picked up by hand. Higher proportions of wrasses, groupers, rabbitfishes, parrotfishes, goatfishes, sweetlips, and spiny lobsters are caught by scuba divers than by snorkelers (Table 2). Greater differences occur at the species level since many species typically inhabit depths beyond the reach of most snorkelers. There are also distinct differences between day and night catches, but separate day and night expansions have not been run.

Participation and Effort

The estimated annual number of boat trips and person trips has fluctuated widely since 1985, ranging from 279 to 1,057 and from 748 to 3,330, respectively. The estimated annual number of boat hours and person hours has also fluctuated widely, ranging from 894 to 2,151 and from 2,293 to 7,119, respectively (Fig. 11).

Catch Rates

Overall catch rates as kg/boat-hour and kg/person-hour have ranged from 5.2 to 9.4 and from 1.5 to 3.1 since 1985, respectively (Fig. 12). The catch rate for the scuba segment has risen sharply over the last 2 years. This is not believed to be indicative of a healthy fishery for nonbiological reasons that are not apparent from the

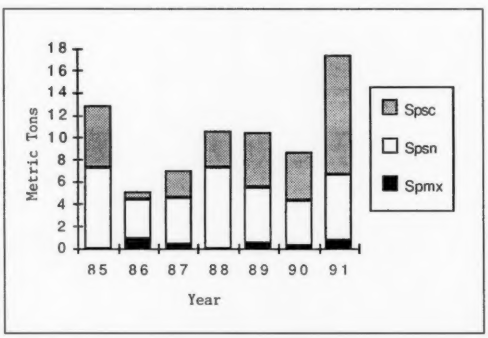

Figure 10.—Estimated annual spearfishing landings utilizing small boats during 1985–91. Spsc = landings exclusively by scuba diving; Spsn = landings exclusively by snorkeling; Spmx = landings by a combination of scuba diving and snorkeling.

Table 2.—Species composition of Guam landings taken by divers during FY 1985–91. All fishes were taken by spear, and invertebrates were taken by hand as well as spear. Taxa comprising less than 1% of total landings are not shown.

	Snorkel only		Scuba only		Unknown or both		All methods	
Taxon	kg	%	kg	%	kg	%	kg	%
Fishes								
Carcharhinidae								
(Requiem sharks)	502.3	1.4	189.2	0.6	0.0	0.0	691.5	1.0
Holocentridae								
(Squirrelfishes)	744.2	2.1	585.7	1.8	89.5	3.4	1,419.4	2.0
Serranidae (Groupers)	1,390.1	3.8	2,714.0	8.4	78.2	2.9	4,182.3	5.9
Carangidae (Jacks)	1,545.0	4.3	210.8	0.7	25.5	1.0	1,781.3	2.5
Lutjanidae (Snappers)	910.8	2.5	978.9	3.0	58.6	2.2	1,948.3	2.7
Haemulidae (Sweetlips)	314.1	0.9	909.2	2.8	18.5	0.7	141.8	1.7
Lethrinidae (Emperors)	643.3	1.8	435.8	1.3	58.1	2.2	1,137.2	1.6
Mullidae (Goatfishes)	408.3	1.1	518.7	1.6	56.5	2.1	983.5	1.4
Kyphosidae (Rudderfishes)	3,241.1	8.9	311.3	1.0	48.9	1.8	3,601.2	5.1
Mugilidae (Mullets)	755.7	2.1	0.0	0.0	0.0	0.0	755.7	1.1
Labridae (Wrasses)	1,524.1	4.2	3,175.6	9.8	477.1	17.9	5,176.8	7.3
Scaridae (Parrotfishes)	12,238.9	33.7	13,152.9	40.7	394.5	14.8	25,786.3	36.2
Acanthuridae								
(Surgeonfishes)	7,215.8	19.9	5,987.2	18.5	341.3	12.8	13,544.3	19.0
Other fishes	868.4	2.4	923.4	2.9	79.1	3.0	1,870.7	2.6
Total	32,301.9	89.0	30,092.7	93.1	1,725.8	64.9	64,120.1	90.0
Invertebrates								
Trochus niloticus (Topshell)	807.7	2.2	197.9	0.6	604.7	22.7	1,610.3	2.3
Tridacna maxima								
(Giant clam)	1,194.1	3.3	6.7	0.0	0.0	0.0	1,200.8	1.7
Octopus spp. (Octopus)	441.9	1.2	208.6	0.6	104.8	3.9	755.3	1.1
Panulirus spp.								
(Spiny lobsters)	1,214.0	3.3	1,635.5	5.1	130.8	4.9	2,980.3	4.2
Other invertebrates	326.4	0.9	194.6	0.6	92.9	3.5	613.9	0.9
Total invertebrates	3,984.1	11.0	2,243.3	6.9	933.2	35.1	7,160.6	10.0
Method totals	36,286.0	100.0	32,366.0	100.0	2,659.0	100.0	71,280.4	100.0
Percent of total catch		50.9		45.4		3.7		100.0

summary statistics. These include greater success at intercepting scuba diving spearfishing parties, particularly those returning late at night, and a shift in effort to deeper water (30–42 m) by parties that consider shallow areas "fished out."

Economics

Spearfishermen often sell their catch, but no economic information is available. Catch disposition is recorded but has never been analyzed. Competition from inexpensive imports probably inhibits growth, which slows the potential for overfishing.

Bigeye Scad Fishery

The bigeye scad, locally called atulai, is a small coastal pelagic species that is cosmopolitan in the tropics, but probably forms a distinct stock in the Marianas. It periodically occurs in large schools in coastal bays and channels as well as from near the surface to depths of >200 m near shore. It typically aggregates inshore during the day and migrates offshore at night. When inshore, bigeye scad are taken by a variety of shore-based methods including teams of people using large barrier nets with the aid of boats and divers. When offshore, they are attracted to lights hung from small boats and jigged. Shore-based methods typically account for 70% or more of the annual landings (Hensley and Sherwood, 1993).

Jigging for bigeye scad by nightlight is done during moonless periods. Prior to 1985, too few returning fishermen were intercepted by the survey, so only the period 1985 through 1991 is presented here. The fishery is highly seasonal; the greatest effort and catches occured during July and August and there is almost no activity or catches from December through April.

The Catch

Estimated annual landings since 1985 have ranged from 3.4–20.2 t with no apparent trend. Good and poor years coincide well with estimated annual landings by shore-based methods (Hensley and Sherwood, 1993), indicating that these results are real rather than the result of inadequate sample size. The largest estimated combined annual catch for Guam for all methods was 76.5 t in 1989. An upper bound of 200 to 440 t for an annual range of harvest for the entire Mariana Archipelago has been suggested (Polovina et al., 1985). This is based on the untested assumption that the abundance per mile of 200 m contour in the Marianas is the same as that in the Hawaiian Islands. For Guam and Galvez-Santa Rosa Banks, the equivalent upper yield would be 50–112 t. No figure is available for Rota Banks and 45° Banks.

Participation and Effort

The estimated annual number of boat trips and person trips has fluctuated

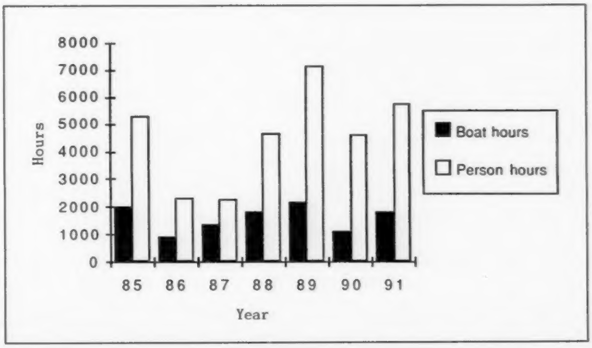

Figure 11.—Estimated annual number of boat hours and person hours spent spearfishing during 1985–91.

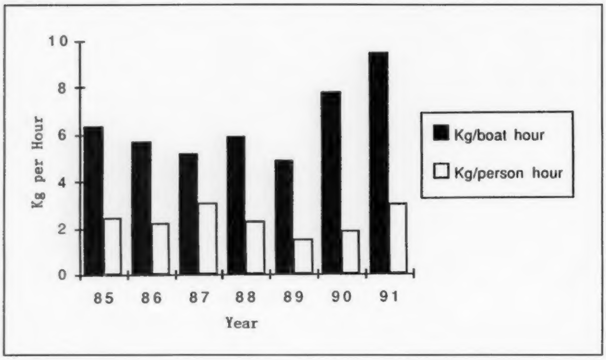

Figure 12.—Catch rates as kg per boat hour and kg per person per hour spent spear-fishing during FY 1985–91.

widely since 1985, ranging from 325 to 1,280 and from 911 to 3,475, respectively. The estimated annual number of boat hours and person hours has also fluctuated widely, ranging from 2,167 to 9,385 and from 5,312 to 26,088, respectively. No clear trends are apparent.

Catch Rates

Catch rates since 1985 have ranged from 1.0 to 3.8 kg/boat-hour and from 0.4 to 1.4 kg/person-hour, respectively, with no apparent trend or correlation with annual landings.

Economics

Bigeye scad are sold by subsistence and commercial fishermen along the roadside, in stores, or directly to restaurants. Bigeye scad and closely related species are also imported fresh from the Philippines. Neither the proportion of the annual harvest that is sold nor revenues have been estimated for this fishery although some sales information is available on the offshore survey data base. An assessment of the economics of this fishery is not possible at this time. Since bigeye scad are usually the single most important inshore species in terms of annual landings, their economic importance must be great.

Discussion

Pelagic Fishery

At present, trolling is the only method used by Guam's small-boat fishery that targets pelagic species. The targeted species are all migratory, high-trophic-level predators. Fish caught in the vicinity of Guam are part of regional or possibly Pacific-wide stocks. Although some species may linger in the vicinity of Guam for a while, they are generally seasonal in occurrence, have very high fecundity, and grow fast. Pelagic species that spend at least the daylight hours >50 m (broadbill swordfish, *Xiphias gladius*; bigeye tuna, *Thunnus obesus*; and albacore, *Thunnus alalunga*) are not locally fished, although there is commercial interest in them.

Annual landings of Guam's troll-caught species are highly variable. There are no apparent trends in the catches of mahimahi, wahoo, skipjack tuna, or sailfish. Catches of blue marlin increased during the past 12 years, whereas catches of yellowfin tuna decreased. Catch rates for blue marlin have increased in recent years, whereas catch rates for skipjack and yellowfin tuna have declined. Increasing charter boat participation and interest in sportfishing rather than commercial fishing are likely causes of increasing catches and catch rates for blue marlin. The low marketability of skipjack tuna is the most likely cause for declining catch rates for that species, but declining catches and catch rates for yellowfin tuna may be stock related. These two tunas as well as bigeye tuna are the principal components of the Guam-based domestic purse seine and foreign longline fisheries which operate primarily in more southern Federated States of Micronesia waters. The impact of these large-scale fisheries on stocks of these, as well as incidentally caught mahimahi, wahoo, blue marlin, and sailfish, are largely unknown, and the data necessary to assess this are not available to U.S. fisheries scientists. However, landings of longline-caught tuna transshipped through Guam are being collected by the Guam Department of Commerce; the South Pacific Commission is collecting data on the purse seine fishery and has a major tagging study of yellowfin tuna in progress. The most complete assessment of blue marlin to date (Skillman, 1989) indicates that it is growth overfished, but that the situation may be improving because of increased use of deep vs. shallow longline gear.

A major complaint by troll fishermen is that they must now travel farther to obtain the same catches they once enjoyed closer to Guam. To evaluate this apparent indicator of possible overfishing, a detailed analysis of catch rates by primary fishing area must be done. Although the necessary information is on the data base, outmoded computer equipment and a shortage of personnel have prevented such an analysis. With the possible exception of yellowfin tuna, there is no other indication of overfishing.

Management of the local pelagic fishery is meaningless because Guam's small trolling fleet does not have the potential to affect the stocks. However, certain beneficial measures have and could be taken. The deployment of FAD's probably helps to attract and hold migrating pelagics closer to Guam. The banning of longlining within 50 miles of the 100-fm contour of Guam and its satellite banks reduces the risk of gear conflicts and prevents the interception of pelagics once they are within the range of the trolling fleet. A similar ban on domestic purse seiners could also benefit the troll fishery, but this is highly unlikely on legal grounds.

The charter and recreational components of the fishery are economically healthy, and continued growth is ex-

pected. However, the health of the commercial component is in decline because of a combination of competition from cheaper, more efficient sources including longline-caught fishes rejected for transshipment and the absence of a unified local marketing effort.

Bottomfish Fishery

The bottomfish fishery appears to be stable, but the dominance of small species with high turnover rates is indicative of a mature fishery in which the larger, long-lived species are overfished. Indeed, two of the most important, desirable, and largest of the deep-water species in "virgin" catches have nearly disappeared in recent years. The grouper *Epinephelus octofasciatus*, which represented 13% of the catch (90% of which were the deep-water component) in the late 1960's and was a prominent component of catches in the relatively unexploited Commonwealth of the Northern Mariana Islands in the early 1980's (Ikehara et al., 1970; Polovina et al., 1985), is now rarely caught and has not even appeared in the sampled catch for most years since 1980. Catches of onaga, *Etelis coruscans*, the single most important species in catches of the late 1960's (25%), have decreased considerably during the past 6 years. However, unchanging mean sizes of 10 important bottomfish species since 1980 (5 shallow and 5 deep) indicate that the fishery is stable.

Polovina and Ralston (1986) calculated an annual equilibrium yield for the 125–275 m depth band of 15.6 t for Guam and 7.8 t for the Galvez-Santa Rosa Banks region (23.4 t total, but this excludes the smaller Rota and 45° banks). The mean annual harvest for the 1980–91 period was about 24 t, 7 of which were deepwater species. The largest estimated annual deepwater harvest was 12.8 t (42.8 t in 1985 for all depths), well under the estimated equilibrium yield. For the fishery as a whole, there is no indication of overfishing.

Since it is impossible to target a given species reliably and the viability of released deep-water species is unlikely, species-specific management measures would not be practical. At some point, a value judgement must be made whether or not to sacrifice the most vulnerable species in return for increased overall yields. Assuming that there is a single archipelagic stock, then as long as there are refuges in the form of lightly fished banks or islands sufficient to insure an adequate spawning stock biomass of key species, no specific management measures are necessary.

The economics of the fishery is complex and poorly understood. Although supply has never met the demand, several factors probably limit participation. These include competiton from inexpensive imports of reef and bottomfishes and a booming economy that offers better opportunities elsewhere. No one depends on bottomfishing to earn a living. There have been no fulltime commercial highliners since the mid-1980's, and increasing annual landings since then are attributable to an increase in the number of participants which are probably primarily recreational and subsistence fishermen.

More effective management of the fishery would be facilitated by a clear separation of deep- and shallow-water effort as well as catches and better consideration of the overlap and interaction of the shallow water component with other competing fisheries. Biological studies of key species are desirable.

Reef-Fish Fishery

Spearfishing is the only significant reef-fish fishery other than the shallow bottomfish fishery which uses small boats. The same stocks are also harvested by shore-based spearfishing as well as other methods. Catch rates have increased during the past 3 years primarily because of an increase in the use of scuba equipment and the tendency of certain "highliners" to shift to deeper water. The sample size is insufficient for statistically significant trends to be detected. To date, biological data on the species have not been examined, nor have there been any studies of the biology of key species. However, anecdotal information suggests that some species, if not the fishery as a whole, are overfished. There is universal agreement among long-time spearfishermen that catches are down considerably from several years ago, and that one has to travel to the least accessible areas or to visit deeper water to obtain worthwhile catches. This author as well as other divers have noticed a decline in many of the larger species during the past 15 years. In comparison to other relatively unfished islands in the region, the community structure of Guam's reef fishes was noticeably different as long as 15 years ago and dominated not only by small species that mature rapidly but also by relatively small individuals of many species. There also seems to be a trend among divers in general, particularly the transient military and nonindigenous population, to take up nonconsumptive activities such as photography. Since this group consists primarily of those with relatively low spearfishing skills, the remaining skilled fishermen could cause the catch rate to increase until biological reasons impact it. However, no statistical significance can be attached to apparently increasing catch rates in recent years because of high variability and small sample sizes.

De facto refugia in the form of seasonal rough water as well as less accessible islands in the CNMI and offshore banks may prevent recruitment overfishing for many species. However, many lagoon and reef-flat species do not benefit from this and are under considerable fishing pressure at Rota and Saipan, the only other islands with these habitats.

New management measures are needed to prevent a decline in this fishery. A network of permanent preserves that encompass a diversity of habitats and that are large enough to ensure the protection of the more mobile and larger, more vulnerable species is needed. This would also reduce the potential for conflicts by satisfying the demands of nonconsumptive users. Species-specific management of the most vulnerable species is also desirable. Restriction of certain practices such as the commercial sale of speared fish or the use of scuba to spear fish, particularly at night, should be considered.

Although no economic information has been summarized, the supply has

never met the demand. However, competition from inexpensive imports keeps prices low and may reduce the pressure on the resource.

Bigeye Scad Fishery

Estimated annual landings since 1985 have fluctuated widely. Good and poor years coincide well with estimated annual landings by shore-based methods, indicating that these results are real rather than the result of inadequate sample size. There is no indication of overfishing. Since the largest estimated combined annual catch for Guam for all methods—84.3 t—falls midway between suggested upper equilibrium yields based on studies in the Hawaiian Islands, this fishery should be closely monitored.

Acknowledgments

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An Overview of Guam's Inshore Fisheries

REBECCA A. HENSLEY and TIMOTHY S. SHERWOOD

Introduction

Background

Since long before the first contact of westerners with native Guamanians (or Chamorus[1]) in 1521, fish has been the primary source of protein for the islanders. Little is known about traditional management of Guam's fisheries, but fishing was and has remained an important part of life and culture. In the past, subsistence fishing provided Guam's residents with an ample supply of fish. Most of the fish caught were consumed by fishermen's families or shared with the community and were harvested from three main areas of the sea: The coral or nearshore shallow adjacent areas, nearshore slopes to about 100 fathoms and the surface ocean waters. Much of the traditional use of fish for social obligations in the form of fiestas (large gatherings for funerals, weddings, christenings) is still practiced.

Guam is a U.S. territory located in the western Pacific (Fig. 1). It is the southernmost and largest island in the Mariana Island Archipelago with over 130,000 people on about 550 km^2. Much of the change in Guam's fisheries, from traditional subsistence fisheries to the more modern subsistence, commercial, and recreational fisheries has occurred since World War II. Johannes (1978) maintained that the decline of the Pacific island fisheries was due mostly to change in the economic system of the Pacific Islands to a more western one which has eroded the ancient marine tenure laws and tra-

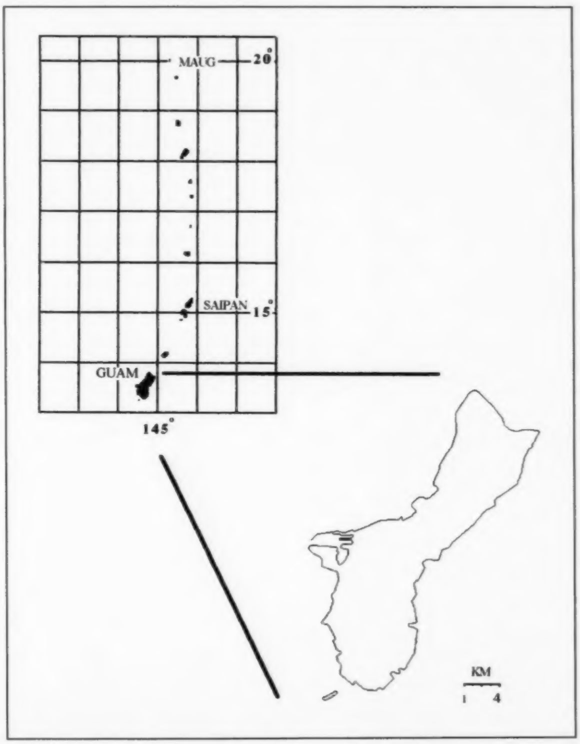

Figure 1.—Guam (13°30'N; 144°50'E) is the southernmost of the Mariana Archipelago.

[1]Chamoru, previously Chamorro, is the currently accepted spelling of the indigenous people of Guam.

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ABSTRACT—Guam's nearshore reef fishery is a multi-gear, multispecies fishery that has undergone major changes through the years. Methods have evolved and become more modern. This, along with the changing economic status of Guam, has severely stressed the fishery. Top targeted species are being overexploited and "growth overharvesting" is occurring; the more serious form of "recruitment overharvesting," is happening to some of the key species. Major management concerns are discussed with respect to overfishing and habitat destruction. Management recommendations for this fishery include gear restrictions, size restrictions, and the establishment of marine conservation areas.

ditional island conservation ethics. This, along with the introduction of more modern, manufactured fishing materials (monofilament nets, steel hooks, poles, reels, spearguns, scuba gear, etc.), has changed the complexion of Guam's inshore fishery and aided in the decline of the nearshore reef fishery. Ikehara et al. (1970) stated that Guam's shallow inner reefs appeared to be fully exploited and showed signs of overfishing. Katnik (1982) found that two heavily fished areas on Guam were overfished and stated that other accessible areas on Guam could be equally overexploited. What was once a well stocked, complex fishery with diverse fishing methods has changed to a fishery under serious fishing pressure.

Scope

Because of the increased efficiency of fishing techniques due to introduction of modern materials and because of the increase in fishermen and the island population, the Guam Division of Aquatic and Wildlife Resources (DAWR) recognized the need to protect the fishery from overharvesting. Initial monitoring of the resources began in the 1960's, and it had evolved by 1982 into the current creel survey methodology adapted from Malvestuto et al. (1978). Because of the different usage and the different areas of the sea utilized for the multispecies, multigear fisheries, Guam's fisheries monitoring was divided into two projects. These were the "inshore" (or nearshore reef) fisheries and the "offshore" (small boat) fisheries (Myers, 1993). The inshore fisheries discussed here will encompass the coral or nearshore shallow adjacent waters which consists mostly of fringe reefs.

This paper describes inshore fisheries, concentrating on data from 1982 through 1991. We discuss fishing techniques and data collection and compilation for landing and effort estimates of Guam's fishery. The harvest components (finfish, nonfinfish, and seasonal juveniles or traditional fishery) and current management practices are described with suggestions for conservation of the fishery.

Guam's Inshore Fisheries

Historic Fishing Methods

Detailed fishing techniques from prehistoric times have been described by Amesbury et al. (1986) and will be only briefly described here. Early fishing techniques (prior to the 1930–40 period) employed gear composed of natural materials. Today, inshore (or reef and lagoon) methods have incorporated modern equipment and have been modified in some manner from the traditional form of fishing. Some form of hook and line fishing, usually handline, has been done since the arrival of the Chamorus on Guam around 1500 BC (Amesbury et al., 1986). Net fishing has included forms of dip netting, bag seining, throw netting, surround netting, drag netting, and gill netting (a more recent form of net fishing). Fishing with traps and spears has occurred throughout the history of Guam. Women historically harvested the seagrass parrotfish (Scaridae) and some wrasses (Labridae) by hand. All social classes of Chamorus harvested eels with iron spears and crabs with multipronged spears. Gleaning for invertebrates has always occurred, especially for mollusks and algae for use as either bait or food. The Spaniards gleaned for sea cucumbers.

Several types of fishing no longer occur. Two of these are the opelu or hachuman fishing (for *Decapterus* sp.) and the decoy method of fishing (Amesbury et al., 1986). Turtles were harvested until 1976 when it was prohibited. Other currently prohibited methods include fish weirs, fish poisoning from root extract (*Barringtonia asiatica* tree), chlorine bleaching, and dynamiting. These are still practiced illegally on a small scale.

Traditional fishing practices are still observed routinely on Guam. One practice is the fishing for seasonal juveniles recruiting to the reef flats (discussed below), while the other practice involves sharing the catch. The catch from the surround net or chenchulu (when used for catching seasonal mackerel or *Selar crumenopthalmus*) is still divided up into thirds with the portions going to the owner of the net, the village where the fish were caught, and those who helped harvest the catch.

Contemporary Fishing Methods

Many of the currently used methods are very efficient because the technology and materials used are readily available at a minimal cost. Contemporary methods include hook and line, net fishing (cast, gill, drag, and surround net), spear fishing (snorkel and scuba), hook and gaff, and "other" methods (a miscellaneous category that includes mostly gleaning for invertebrates). These methods, modified through time, are described below and account for the harvest of over 100 species of finfish and 40 nonfinfish species (3 lobster, 9 crab, 24 mollusk, and 4 echinoderm)[2] (Amesbury et al., 1986, 1991).

Currently, the most popular fishing method on Guam is hook and line. This technique ranges from the use of handlines to rod and reel with lures or baited hooks. Recently, we have observed fly fishing in Guam's waters.

The majority of the fish harvested are taken by net fishing. All types of net fishing done today, except gill netting, have long histories on Guam. Net mesh sizes range from 1/4-inch stretch (for seasonal juveniles) to greater than 3-inch stretch. The cast net or throw net (talaya) is one of the few nets that are still hand woven (using monofilament) by the traditional talaya fishermen[3]. These nets vary in mesh size and number of pockets depending on the fish targeted.

Other than the modern equipment, drag netting has changed very little through time. It still is the simplest form of net fishing where the net is

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[2]This identifies all information, unless otherwise cited, obtained by the authors from Guam Fisheries Investigations-Project FW-2R-26 Job Progress Reports (Jobs: F-F1–2 Inshore Fisheries Survey; F-F1–3 Fisheries Data Processing; F-F1–8 Studies of Recreationally Important Reef Fish). Information can be obtained from the Division of Aquatic & Wildlife Resources (DAWR), Dept. of Agriculture, P.O. Box 2950, Agana, Guam 96910.

[3]D. Narcissi, Talaya fisherman, Guam Environmental Protection Agency, Harmon, Guam 96912. Personal commun.

pulled through the water as the fish are driven into the net. Today, this method is most often, but not always, used at night.

The use of the surround net or chenchulu has occurred for many years. Today, two types of surround netting occurs. In the first type, two people transport the net through the water on two large inner tubes. The fishermen begin setting the net in a 'U' shape and close the net into a circle as a second group of people drive the fish into the net. Once the net is set, the fishermen dive into the enclosure and harvest the fish by spear and/or hand. The second form of the surround net, also called the atulai gill net (Amesbury et al., 1986), is one that is used to harvest seasonal mackerel or atulai. This net is most commonly used in the harbors, channels, or bays. When a school of atulai is sighted, a boat surrounds the fish with the net and the school can be harvested over a period of days.

Gill net fishing is the most recent form of net fishing on Guam. This method is very popular (usually ranking in the top three of all methods used). This popularity is due to the availability of the gill nets, the comparative low cost, and the effectiveness of the modern monofilament materials. The net is used at any time of the day or night, but it is most successful on an ebb tide where fish escaping the shallows are gilled in the net.

Spearfishing has undergone a vast change with the advent of modern equipment, evolving from handmade spears and freediving to spearfishing with scuba gear. Spearfishing with snorkel and spearfishing with scuba target different fishes and are considered separate techniques. Because of the highly selective nature of both of these methods, spearfishing harvest consists of fish of larger species (i.e., humphead parrotfish, *Bolbometopon muricatum*) than other fishing techniques.

The remaining two methods are primarily used for harvesting nonfinfish. The use of hooks and gaffs targets octopus, although some mantis shrimp and miscellaneous fish are also caught. The last method, a catch-all category appropriately called "other," generally includes gleaning for nonfinfish. New or little-used techniques like dip netting and mantis shrimp traps fall into this miscellaneous category.

Inshore Creel Survey

The primary objective of the inshore fisheries survey was to obtain the most accurate estimate of the total annual inshore fisheries harvest in order to monitor and manage the resource. Fishing activity has been monitored since the early 1960's when much of the early information was taken by DAWR conservation officers (law enforcement personnel). Monitoring changed over the years, as did fish identification. The early 1960's catch was identified by the Chamoru name of the fish. Problems with catch composition arose because one name could mean any wrasse species, parrotfish would be identified by color (blue, brown, white, and green), and rabbitfish would be identified by at least five names that described the fish by size. As taxonomic skill increased, the catch was reported in increasing detail.

Working closely with the U.S. National Marine Fisheries Service, the DAWR developed a program for analyzing the inshore fisheries. Since the installation, all the data collected has been analyzed by this program. In 1991, we modified and restructured our analysis to allow comparison of data from 1982 to the present. (Because of methodological changes, data prior to 1982 do not lend themselves to analyses.)

Survey Methodology

Because much of the shoreline is inaccessible to most fishermen (i.e., military bases, clifflines), not all of Guam is surveyed. Data collection for the inshore fisheries expansion is conducted in an area representing 85% of the total fishing participation (verified from shoreline usage seen during aerial surveys). A two-part roving creel survey, effort (or participation) and catch, is performed for both day and night (begun in 1985) to provide sufficient data to allow for 90% confidence limits for the inshore analysis. Detailed methodology and analyses are described in Amesbury et al. (1991).

During an effort survey, a surveyor records all active fishing participation (time of day, location, number of people, number of gear units, fishing methods, reef zone fished, weather conditions, and surf conditions). Counts are made of fishermen and gear and are used to estimate effort in terms of person-hours (p-hr) and gear-hours (g-hr). The catch survey is of the roving fisherman-intercept type and requires as many interviews for as many fishing methods as possible. The survey variables collected include fishing method, number of fishermen, bait type, number of gear, mesh size, interview time, trip length, species caught, numbers of catch species, and individual weights and lengths. Catch data is used to estimate overall landings (kg), CPUE, and species composition.

The majority of the species caught are represented with this methodology. Species that recruit en masse, like mañahak (rabbitfish) or atulai, cannot be adequately represented in the current creel survey. Catch estimates of these species are obtained when the recruiting runs occur and are added to the survey expansion catch values to obtain the yearly inshore harvest.

Finfish

Finfish are the primary harvest (usually >95%) of contemporary fishing methods. This harvest includes all sizes of reef fish, even the highly anticipated seasonal runs of juveniles. Deepwater and/or pelagic fish, normally harvested using offshore techniques, are occasionally caught using inshore methods. Over 100 species of finfish are harvested in the inshore fishery. The primary families include: Acanthuridae, Carangidae, Gerreidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mugilidae, Mullidae, Scaridae, and Siganidae. The top ten species caught in the inshore fishery, not including seasonal juveniles, are *Naso unicornis, Caranx melampygus, Siganus spinus, Mulloides flavolineatus, Lethrinus harak, Valamugil engeli, Kyphosus cinerascens, K. vaigiensis, Cheilinus fasciatus*, and *Gerres* sp. Ranking of these species changes as fishing pressure and gear use fluctuates.

The harvest of one of these key species, *Mulloides flavolineatus*, best describes what is occuring in the finfish fisheries. By 1991, the harvest declined by 90% over a 6-year period (from 33,896 to 3,417 kg). The 100–150 mm size class is targeted in the traditional fishery, which prevents many fish from reaching larger size classes and further impacts the reproductive potential of the population. The downward trend in overall harvest is characterized by the absence of larger females that represent the major portion of the spawning potential.

Many of the once economically important larger species, like the humphead parrotfish, *Bolbometopon muricatum*; wrasse, *Cheilinus undulatus*; groupers over 25 kg, and snappers are rarely seen in Guam's waters, much less reported on the inshore survey catch reports. Interest in the harvest of aquarium fish is on the rise, while the actual harvest appears to be declining. These fish may be less susceptible to overfishing because of their high turnover rate, but problems are beginning to surface with respect to the use of chemicals for fish collecting, habitat destruction, and unmonitored or illegal catches.

The harvest of recruiting juvenile fishes (Table 1) makes up Guam's traditional finfish fishery. It historically has been and still remains an important part of the nearshore reef fisheries. Seasonal juvenile harvest can range from a minor component of <1% (in 1982–83) to over 50% of the overall harvest (in 1991).

Two major components of the juvenile harvest are mañahak and atulai (Fig. 2). The local residents anxiously await the recruitment of both species to the nearshore reef waters. Even though the yearly run of mañahak does not always occur, fishermen will gather at the shoreline during the first few days of the last quarter lunar phase of the expected recruitment period. The mañahak recruit onto the flat area of the reef in aggregations or "balls", as they undergo morphological development from planktivorous to herbivorous fish (Kami and Ikehara, 1976). The largest, as well as the most economically valuable, catch of mañahak is prior to the complete coloration and dietary change (the first 1–2 days on the reef). Harvesting of mañahak is conducted with all nets using a $^1/_4$–$^1/_2$ inch stretch mesh size. Atulai usually begin their seasonal runs into inshore waters by the age of 4 months (Amesbury et al., 1986). The atulai are harvested with surround nets, cast nets, and by hook and line and usually represent the majority of the seasonal harvest.

The recruitment of other juveniles, like i'e' (jacks), ti'ao (goatfish), en masse and aguas (mullet), do not occur like the mañahak or atulai, but they are still heavily fished. The recruitment periods for these juvenile fishes often overlap and peak harvests are seen every 3–4 years. The harvest of these juveniles is primarily by net fishing

Table 1.—Seasonal juvenile fishes targeted in Guam's traditional finfish fishery. Chamoru names are after Kerr (1990).

(English Name) Chamoru name	Family and species targeted
Aguas (mullet)	Mugilidae
Atulai (bigeye scad, mackerel)	Carangidae; *Selar crumenopthalmus*
Achemsom[1] (fusilier)	Caesionidae
I'e' (jacks)	Carangidae; primarily *Caranx melampygus*
Mañahak (rabbitfish)	Siganidae; *Siganus spinus*, *S. argenteus*
Ti'ao (goatfish)	Mullidae; *Mulloides flavolineatus*

[1] Many local fishermen use this name to incorrectly identify juvenile fusiliers when they recruit en masse. Achemsom actually means small rainbow runner (Carangidae; primarily *Elegatis bipinnulatus*).

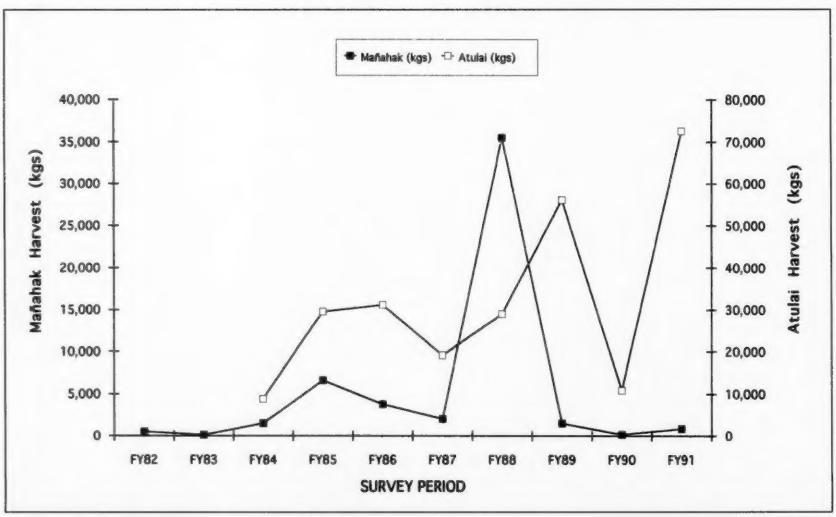

Figure 2.—Estimated harvest from 1982 through 1991 of two of Guam's seasonal juveniles (mañahak = young rabbitfish, primarily *Siganus spinus*; atulai = young mackerel, *Selar crumenopthalmus;* FY = 12-month fiscal year). Names are after Kerr (1990).

(using 1/4–1/2 inch stretch mesh size), except the i'e' which are often harvested by hook and line.

Nonfinfish

Until recently, the funding constrained the DAWR to work on finfishes only; therefore, information on nonfinfish is limited to catch statistics for methods that also target finfish. Since harvesting of invertebrates is one of the less frequent and easily missed activities (i.e., virtually all lobsters are taken by spearfishing), our nonfinfish harvest is probably underestimated. For a few of the species most often collected, the true annual catch is probably only a few metric tons at most.

The coral reef is Guam's single most valuable resource, and, over the years, coral has been harvested for ornamental and commercial use. The most common corals harvested commercially in the past included *Acropora*, *Antipathes*, *Fungia*, *Heliopora*, and *Tubipora* sp. (Hedlund, 1977). Coral (dead or live) is no longer legally collected without a permit (now issued for educational or research purposes only), and the regulation is strictly enforced.

Two species of green algae (*Caulerpa racemosa* and *Codium* sp.), two species of red algae (*Gracilaria edulis* and *Asperagopsis* sp.) and one species of brown algae (*Sargassum polycystum*) are commonly harvested (Hedlund, 1977). The green algae or seaweed is seasonal (usually January through May) and when collected, is often sold at local markets. Sargassum and *Enteromorpha* sp. are also collected as bait for rod and reel fishing for herbivores[4].

Many molluscan species have been and are still harvested on Guam. About 15 bivalve species (3 of which are tridacnid clams) have been harvested on Guam (Stojkovich and Smith, 1978). Other shelled mollusks collected include *Trochus* sp. (topshell or aliling), chitons, conchs, nerites, and strombids (Smith, 1986). A few of these mollusks (plus some not mentioned) are collected for ornamental use. The octopus is the most sought after unshelled mollusk; squid and cuttlefish form part of the incidental catch. Of all these, only *Trochus* has a fisheries potential and is currently regulated with size restrictions and is strictly monitored.

Crustaceans make up a major portion of the nonfinfish catch. About nine species of crab are hunted, including land and marine crabs. *Carpilus maculatus* (7–11 crab) and *Etisus splendens* are primarily targeted, whereas *Calappa hepatica* and rarely *C. calappa* (box crabs) are taken as incidental catch during net fishing, spearfishing, or gleaning. Two species of land crabs (*Cardisoma carnifex* and *Birgus latro*) are also highly prized, but are not monitored on the inshore fisheries surveys. Lobster catches are highly prized. The following species are identified in Guam's catches: Palinuridae (*Panulirus longipes*, *P. ornatus*, *P. pencillatus*, *P. versicolor*), Homaridae, and Scyllaridae. The spiny lobster, primarily *P. pencillatus* and the slipper lobster, *Scyllarides squamosus*, are the two main components of the inshore lobster catch and are harvested by spearfishing and "other" techniques (i.e., gleaning). Mantis shrimp, another crustacean, is often mistaken for lobster by some fishermen. It is harvested by hooks and gaffs, shrimp traps, and through incidental catches.

Smith (1986) stated that other invertebrates harvested have included two species of sea urchins (*Tripneustes gratilla* and *Echinometra mathaei*), two species of sea cucumbers (*Stichopus horrens* and *Holothuria atra*) and a freshwater shrimp (*Macrobrachium* sp.). The sea urchin *T. gratilla* has been harvested for ripe gonads. The harvest of sea cucumbers is sporadic (*H. atra* is the most common species harvested). Present harvest is less than that reported in the late 1800's, when catches of 2–3 tons were documented (Amesbury et al., 1986).

Five species of sea turtles have been identified in Guam's waters[5]. Harvest of sea turtles on Guam was prominent prior to World War II and occurred legally until 1976. Inshore catch reports for 1967–68 noted landings of over 80 turtles in 18 months, the largest individuals weighing an estimated 450 pounds. It is currently difficult to determine the extent of the actual catch because of the illegal nature of this activity. Examples of significant poaching activities were seen during a 2-week period in 1990–91, when an estimated 20 turtles (in two separate incidents) were poached.

Catch and Effort Estimates

Overall catch values for 1982–91 for all fish caught (finfish, nonfinfish, and seasonals) for both day and night are shown in Figure 3. In 1990, the participation declined to less than 50% (42,294 fishermen) of the 1984 high (107,391 fishermen). Similar trends for effort and catch are seen (Fig. 3) where the highs occurred in 1984, but lows occurred in 1989 and 1990. Effort and participation increased in 1991 and are attributed to an excellent year for seasonal juvenile harvest. If harvest estimates for atulai and mañahak (Fig. 2) were removed from the catch values, the overall harvest falls between 1989 and 1990 estimates. The 3–4 year pulse of other juveniles (i'e', aguas, and ti'ao) was also observed in 1991 and falsely elevated the survey estimates (number of participants, gear, catch, etc.). If the juvenile harvest values were removed from all years, the 1991 harvest estimate would still be smaller than any previous year.

Day Fishing Estimates

Day harvest and effort values for means for reef fisheries during 1982–91 are shown in Figure 4. A 60% decline in the number of fishermen occurred in 1990 (30,396) from a high in 1984 (97,603). Similar trends for inshore finfish are seen for both effort and catch (Fig. 4) where highs occurred in 1984. Catch follows effort until 1988 when harvest continues to drop while the effort increases. Nonfinfish effort declined over 90% by 1989 (2,759g-hr) from a high in 1982 (28,613 g-hr). Harvest of nonfinfish, though underestimated, declined from 29,499 kg in 1982 to 1,289 kg in 1990. Both

[4]R. A. Hensley, DAWR, P.O. Box 2950, Agana, Guam 96910. Personal observ.

[5]Hensley, R. A. The distribution and abundance of marine turtles from 1966 to 1992 in the waters of Guam. Texas Parks and Wildlife Department, 1231 Agnes St., Corpus Christi, TX 78401. Unpubl. manuscr.

finfish and nonfinfish show declines in effort and harvest estimates for 1988–91 as compared with the 1982-87 period.

Night Fishing Estimates

During the night surveys from 1985 through 1991, effort reached a high for finfish in 1987 (58,893 g-hr) and declined more than 50% to a low in 1990 (25,181 g-hr). Night harvest of finfish rose to a high of 23,538 kg in 1988 before declining to less than 50% in 1991 (10,285 kg). Nonfinfish showed little change in effort until the drop in 1989–90 (from >2,000 to 340 g-hr). The overall night harvest was composed of nonfinfish harvest that ranged from 3.2% (361 kg) in 1989 to 23% (4,684 kg) in 1986.

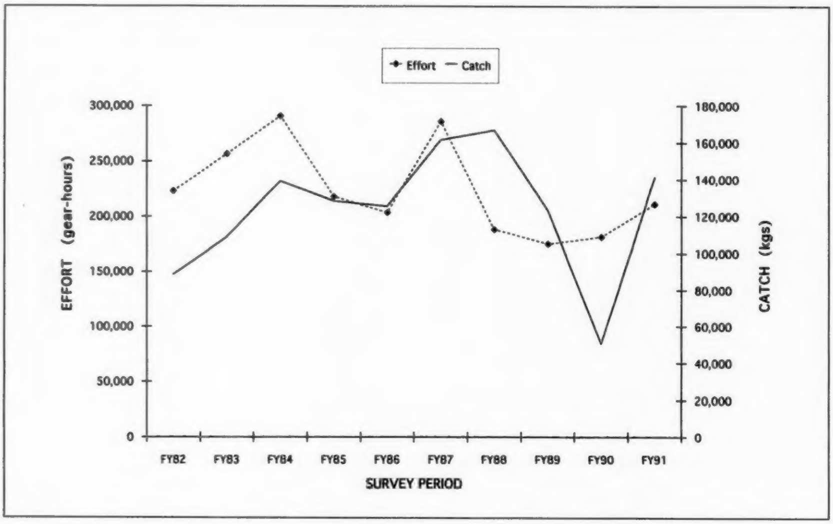

Figure 3.—Estimated effort and harvest of Guam's nearshore reef fisheries from 1982 through 1991 (catch = harvest of all finfish and nonfinfish for both day and night, FY = 12-month fiscal year).

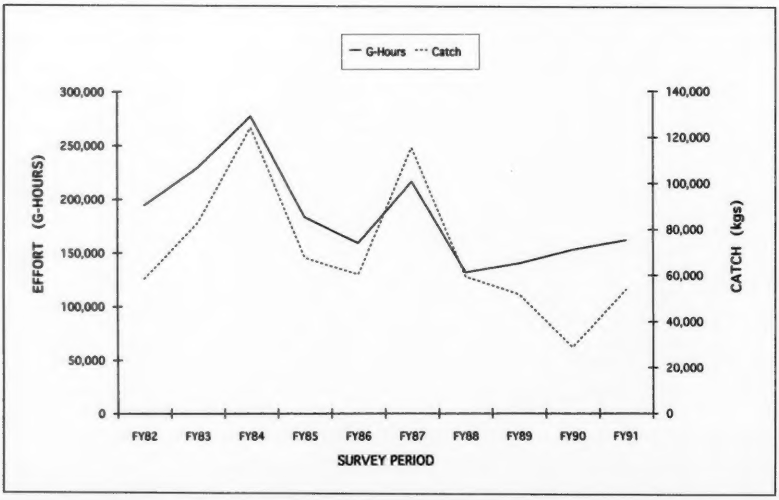

Figure 4.—Estimated effort catch of Guam's inshore fisheries for the daytime from 1982 through 1991 (catch = total harvest of finfish without mañahak or atulai harvest, FY = 12-month fiscal year).

Gear Usage and CPUE

The most popular fishing methods for day and night are seen in Figures 5 and 6, respectively. Hook and line is the most popular method for both day and night, but consistently has one of the lowest CPUE's (catch per unit of effort) ranging from 0.05 to 0.36 for both day and night. The second and third most popular methods for day fishing are cast and gill net. During 1982–84, "other" displaced gill net from the top three. After 1985, most of the participation can be seen with the top three methods (hook and line, cast net, and gill net).

Figure 6 shows the most popular night fishing methods. Spearfishing with snorkel gear ranks second, more often than gill net, drag net, or "other"methods. Except in 1985, when "other" displaces gill net from its third ranking, gill net fishing has increased in popularity where it ranked second for 1986–91.

Many gear use fluctuations are due to the popularity of methods with high CPUE's. The highest day CPUE's (usually about 2.0–4.7) are most often seen with net fishing (mainly drag net, surround net, and gill net) followed by slightly lower CPUE's for spearfishing with scuba and "other". Night CPUE's fluctuate more than day CPUE's and are highest for spearfishing, drag netting, and gill netting. Much of the CPUE fluctuations, especially with net fishing methods like cast, drag, and gill net, can be attributed to the seasonal aspect of the fisheries with respect to traditional fish harvests.

Research

The DAWR has been involved in many aspects of research. For many years, aquaculture potential for freshwater finfish was investigated. Currently, aquaculture research is still conducted (marine finfish and invertebrates) and involves another government agency, private companies, and the University of Guam. Most recently, DAWR began a study of the feasibility of restocking the giant clam *Tridacna derasa*. Studies on the biology and life histories of some recreationally important fishes began in 1984. To date, *Siganus spinus* and *Mulloides flavolineatus* biological profiles have been completed, with *Lethrinus harak* in progress. These biological investigations have been aided by the graduate program at the University of Guam where students investigate important species like *Acanthurus triostegus*, *A. lineatus*, and *Naso literatus* (Molina, 1983; Davis, 1985). Even with the research being done by local and visiting scientists, there is still an enormous amount of information lacking on Guam's fishes.

Work toward identifying the many fish species in Guam's waters has occurred (Kami et al., 1968; Kami, 1971, 1975; Myers and Shepard, 1980; Shepard and Myers, 1981; Amesbury and Myers, 1982; Myers, 1988, 1989). This documentation continues as new species are recorded. The species composition of the fishery on Guam has been made possible by the various check-lists of the fishes in Guam's waters. Aerial surveys are periodically performed to monitor inshore fishing activity in nonsurveyed areas of Guam. Incidental information acquired includes offshore fishing information and turtle abundances[5].

Future investigations are planned for other recreationally important reef species to make sound management suggestions (size, bag limits, seasonal closures). Otolith work has been initiated through the University of Guam.

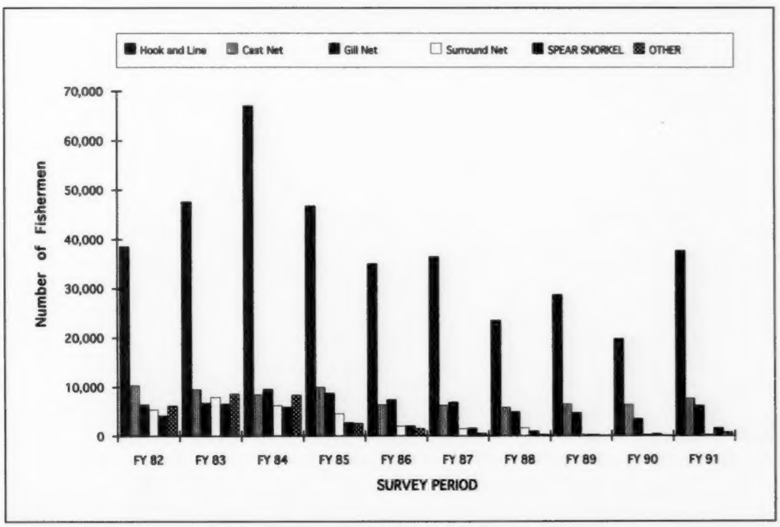

Figure 5.—The most popular fishing methods in Guam's inshore fisheries for the day from 1982 through 1[illegible] (number of fishermen = number of people using specific method; FY = 12-month fiscal year.)

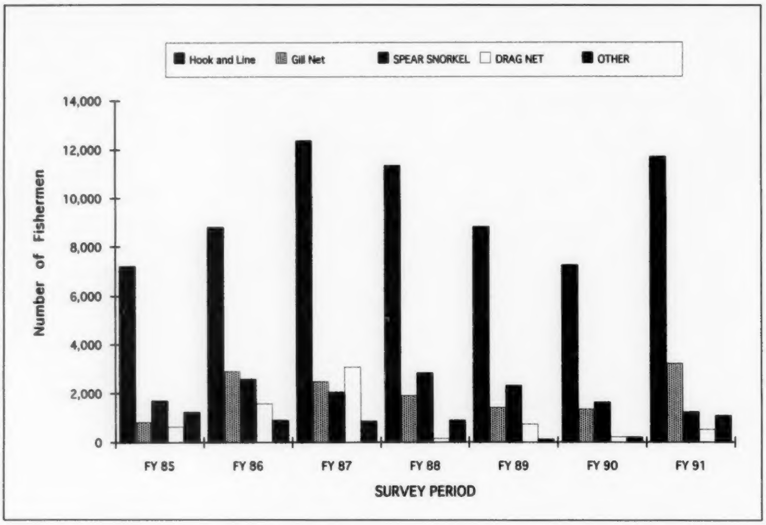

Figure 6.—The most popular fishing methods in Guam's inshore fisheries for the night from 1985 through 1991 (number of fishermen = number of people using specific method, FY = 12-month year).

Analyses of the stocks and future fishing potential is continuing through the modifications in existing expansion methodology and creel survey information[6].

Management Concerns

As the human population grows, modern fishing techniques improve, and fish stocks decline, the need for the management of Guam's tropical coral-reef fisheries increases in order to protect the reef habitat from overfishing as well as from pollution and destruction. The effects of pollution are seen as a result of development and population growth. Much of Guam's southwestern coral reefs are covered with silt from freshwater runoff. Because water quality is extremely important to viable coral reefs (and fish populations), strict standards for development, land clearing, and chemical use should be initiated and enforced. Other major causes of reef destruction includes the use of explosives and poisoning (chlorine bleach and *Barringtonia* root) as fishing methods. Both types of fishing are illegal, but through an education program (with respect to problems associated with destructive fishing practices) and strict enforcement, these have been declining.

Besides pollution and destruction of the reef habitat, it is imperative that a comprehensive management program be established for Guam's fisheries. There are enough indicators that fishing pressure on Guam's inshore resources has reached the point of overexploitation of many of the key species. The proportion of juvenile fish in fisheries landings is increasing rapidly. "Growth overharvesting" has been occurring, and the overall yield has declined as a larger and larger portion of smaller fish are harvested. It is very likely that "recruitment overharvesting," where the reproduction and recruitment of the stocks show a decline, is currently occuring in some of the recreationally important species.

Management Recommendations

Currently, there are several seasonal, area, gear, and size restrictions and bag limits on Guamanian fisheries. These pertain mostly to nonfinfish such as the spiny lobsters, tridacnid clams, *Trochus*, and crabs. Gear restrictions are the only regulations pertaining to finfish harvest. Minimum mesh sizes of $1\frac{1}{2}$ inches on gill nets (except for traditional or juvenile harvest) and hook restrictions for atulai (no snagging) are the principal restrictions. Other gear restrictions include length and time limits for gill net fishing and the prohibited use of fish weirs.

New regulations are currently awaiting approval with one of the most promising avenues being the development of marine conservation area(s). These should be established to provide a refuge for recreationally important fish so they can grow, mature, and reproduce to increase stock health and recruitment. Besides the ability of an area closure to protect fish from harvest, there are many other benefits that make this an increasingly popular form of management and conservation. The closure limits the catches on adjacent reefs without closing down the entire fishery and provides areas where user conflicts are minimized.

Gear restrictions should be implemented and enforced. Because no other method for the seasonal harvest (with mesh sizes as small as $\frac{1}{4}$ inch) is as

[6]Hensley, R. A., and T. S. Sherwood. Unpubl. data. Texas Parks and Wildlife Department, 1231 Agnes St., Corpus Christi, TX 78401.

dangerous to the entire fishery as the nonselective method of gillnet fishing, this method should be heavily regulated. The minimum mesh size for gill nets should be 3 inches, maximum length of time used should be decreased, and it should be required that all nets be manned at all times. The use of gill nets for juvenile fish harvest should be eliminated (except atulai where a $1^1/_2$-inch minimum mesh size should be kept). Other nets, like cast nets and drag nets could still be used for juvenile harvest without the damage to the fish stocks that gill netting may cause. All commercial fishing for seasonal juveniles using nets with mesh sizes less than $1^1/_2$ inches should be prohibited. Because of the environmental damage that sometimes occurs with drag nets, the use of this method should be restricted to specific areas where minimal destruction of habitat would occur. Spearfishing with scuba gear should be prohibited because the few remaining large fish of overexploited species are being targeted.

Appropriate management strategies are difficult to develop when dealing with multispecies, multigear fisheries. Management is further impeded by the desire to hold on to traditional fishing activities which involve the harvest of juvenile fishes. To ensure that future generations enjoy the traditional harvest of juveniles as well as other fishes, strict management regulations must be implemented. Of course, the ability of any management approach also depends on ensuring a healthy and clean reef environment to provide adequate habitat and optimal reproduction.

Market Description

The DAWR has been keeping track of the catch sold by offshore recreational fishermen (Myers, 1993) and has recently begun to document other catches, including nearshore reef fishes. The market for nearshore reef fish has increased on Guam, especially with the diverse cultures that eat fish as a primary source of protein. With the influx of new people and the desire for local fresh fish, the market continues to expand. Because the prices are high, with the average price of $3–4/pound for whole reef fish, the financial benefit for fishermen using a high CPUE method (gill net, surround net, drag net) is enormous. Many of the net fishermen encountered on the inshore survey are no longer subsistence fishermen but are commercial fishermen.

Reef fish imports from Belau and the Federated States of Micronesia are increasing. It is difficult to determine the amount of fish imported because few restrictions are placed on importation. Further difficulties occur in monitoring sales of local and imported fish because of the manner in which they are sold. Many fishermen sell their catch on the roadside, while others sell to small local stores or the large supermarkets. Continued monitoring is necessary to obtain more knowledge of the commercial aspect of the inshore fisheries.

The Future

The outlook for Guam's inshore fisheries, given the current catch information, is poor. If management strategies are not incorporated soon, the remaining fishery may continue to decline to the point of poor productivity. The need for fishery imports will continue to increase as local stocks decline. This lower abundance and availability of Guam's fishery resources could cause higher fishing pressure on neighboring islands.

The ability to manage Guam's fisheries is limited by local politics. In an effort to protect the traditional fishing practices of the Chamorus, legislation has been passed without any apparent foresight of impact on other aspects of the fishery. Interpretation of the term "traditional" has allowed fishing practices acquired since WWII (i.e., gill netting) to continue with little to no regulation. If allowed to continue, the change from subsistence fishing to "traditional" commercial fishing will continue to strain Guam's fishery resources.

The picture is not as bleak as it may appear, however, because many Guamanians are beginning to become environmentally aware. This is demonstrated by the increasingly high number of informants regarding illegal fishing practices (turtle poaching, coral harvesting, gill net abandonment, etc.). The DAWR continues to address the aspect of educating tourists (over 740,000 in 1990) and temporary workers from foreign lands about local regulations. As Guam's population and a need for housing increases, illustrated by the recent closure of the U.S. military bases in the Philippines and the subsequent transfer of 2,000 families to Guam, we see greater threats to the reef resources than we have now. With the help of the general population and the passage of rigid regulations, there is still hope for the fishery to rebound. However, it is highly unlikely for future harvests to reach pre-1987 totals.

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Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, the *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 12, "A List of Common and Scientific Names of Fishes from the United States and Canada," fourth edition, 1980. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

Tables and Footnotes

Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

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Title the list of references "Literature Cited" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, and the year, month, volume, and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

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All figures should be clearly identified with the author's name and figure number, if used. Figure legends should be brief and a copy may be taped to the back of the figure. Figures may or may not be numbered. Do not write on the back of photographs. Photographs should be black and white, 8 × 10 inches, sharply focused glossies of strong contrast. Potential cover photos are welcome, but their return cannot be guaranteed. Magnification listed for photomicrographs must match the figure submitted (a scale bar may be preferred).

Line art should be drawn with black India ink on white paper. Design, symbols, and lettering should be neat, legible, and simple. Avoid freehand lettering and heavy lettering and shading that could fill in when the figure is reduced. Consider column and page sizes when designing figures.

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